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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : H04J 14/02	A1	(11) International Publication Number: **WO 97/06617** (43) International Publication Date: 20 February 1997 (20.02.97)

(21) International Application Number: PCT/GB96/01890

(22) International Filing Date: 2 August 1996 (02.08.96)

(30) Priority Data:

9516048.7	4 August 1995 (04.08.95)	GB
9526219.2	21 December 1995 (21.12.95)	GB
9600814.9	16 January 1996 (16.01.96)	GB

(71) Applicant *(for all designated States except US)*: STC SUBMARINE SYSTEMS LIMITED [GB/GB]; Christchurch Way, Greenwich, London SE10 0AG (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: JONES, Kevan, Peter [GB/GB]; 6 Holly Villas, Ashprington, Totnes, Devon TQ9 7UU (GB). KENDRICK, Simon, James [GB/GB]; 26B Bromley Grove, Shortlands, Bromley, Kent BR2 0LN (GB).

(74) Agent: LAWRENCE, Richard, Anthony; Elkington and Fife, Prospect House, 8 Pembroke Road, Sevenoaks, Kent TN13 1XR (GB).

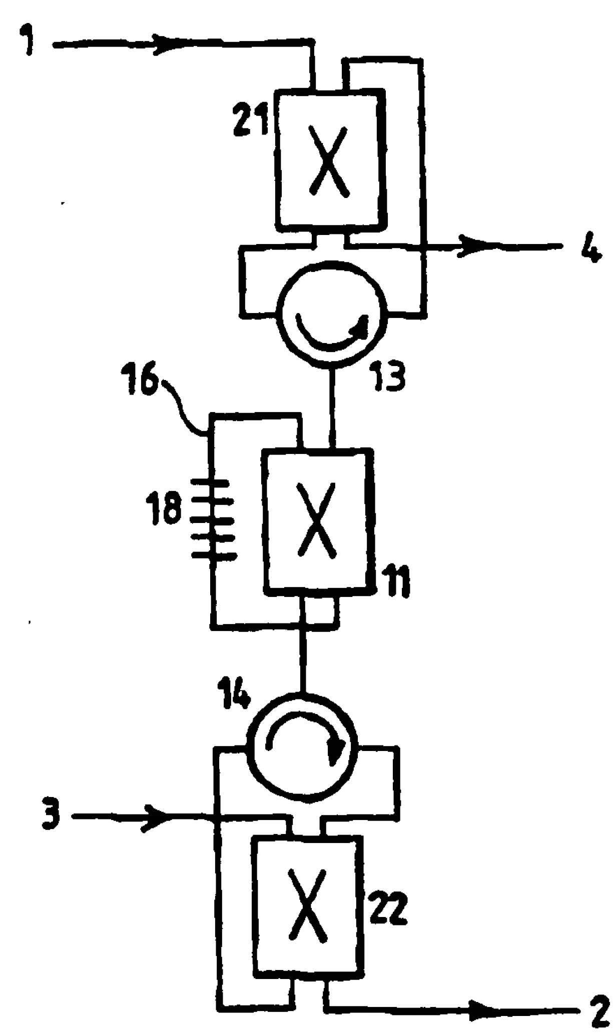
(81) Designated States: CA, CN, JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: SIGNAL ROUTING FOR FIBRE OPTIC NETWORKS

(57) Abstract

Apparatus and methods for signal routing within fibre optic networks are described. Switching means (11, 18, 21, 22) are provided within or outside the ports of an add/drop multiplexer having passive optical components such as circulators (13, 14) to change the routing of signals at predetermined carrier wavelengths, for example between ports of a branching unit. This can be used to divert all signals away from a given port of a branching unit, or to add capacity to a particular path. The switching principles employed can be extended to other forms of wavelength routing element and add/drop multiplexers.



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SIGNAL ROUTING FOR FIBRE OPTIC NETWORKS

The present invention relates to apparatus and methods for signal routing within fibre optic networks, and particularly to use of switching within a branching unit of a fibre optic network. Such switching is particularly adapted to use either within, or to determine routing of signals to, an add/drop multiplexer. The invention extends in further aspects to an add/drop multiplexer comprising switching means, and to a branching unit for a fibre optic network comprising switching means, or comprising an add/drop multiplexer associated with switching means as indicated above. The invention also relates to switchable wavelength routing elements.

As is discussed in the applicant's copending International Patent Application, filed on the same date as the present application and entitled "Add/drop Multiplexer", the content of which is incorporated herein by reference, it is possible to construct a branching element for a fibre optic component which is essentially passive. An schematic example is shown in Figure 1A, comprising a branching element 105 having a first branch 101 for carrying signals to and from a first part of a fibre trunk, a second branch 102 for carrying signals to and from a second part of the fibre trunk, and a third branch 103 for carrying signals to and from a spur station. Although each of the "branches" 101,102,103 is shown here as a single fibre, this is only for ease of illustration: it is possible for each of branches 101, 102, 103 to comprise a plurality of fibres. Branches 101, 102 generally will comprise two or more fibres, one or more to carry traffic in one direction and one or more to carry traffic in the opposite direction. Signals at specific carrier wavelengths are routed by the system so that they are directed out of the branching element according to their carrier wavelength. In an

exemplary case, signals arriving on branch 101 are allowed to pass out to branch 102, except at carrier wavelength λ_1, when they are diverted to branch fibre 103. New signals λ_1' at the same carrier wavelength are added to the branching element from the spur station along branch 103 and are passed out of the branching element along branch 102. Similarly, signals entering the branching element along branch 102 pass out on to branch 101, except at a different carrier wavelength λ_2, at which signals are dropped to the spur station along branch 103, and replaced with other signals λ_2' at this wavelength entering the branching element along branch 103 and passing out along branch 102.

A passive branching element such as indicated above can be designed to have considerable advantages: it can employ relatively few components and can be constructed so that it should not require attention at any point during its working life. Such an element is particularly suitable to use in undersea cable networks. However, it would be desirable even in this area to be able to switch a branching element to at least a limited degree. One desirable option is shown in Figure 1B: as well as dropping λ_1 from trunk 101 to spur 103, λ_3 is dropped and replaced with a new signal from spur 103 at the same carrier wavelength. Alternatively, λ_3 could be dropped instead of λ_1. Ability to provide such features may allow the network as a whole to be reconfigured (for example, by the addition or removal of spur stations to or from the network, or by the addition of capacity to the spur node) without any need physically to change or replace individual branching units already in place.

Further desirable options are shown in Figures 1C, 1D and 1E. These all relate to a break in either the trunk or the spur. All these options are of assistance in allowing traffic to still be transmitted even after such a break has occurred by routing all traffic away from the

broken branch. In the Figure 1C case of a broken spur fibre 103, all traffic to the spur is routed on to one or the other of the trunk branches 101, 102. It then passes through a preceding or a subsequent alternative branching unit and spur station (the alternative branching unit being modified, for example, by being adapted to add and drop additional carrier wavelengths by switching from a Figure 1A configuration to a Figure 1B configuration) and then transmitted between the fibre break spur station and the alternative spur station by means of a back-haul network (e.g. a land line) between the two stations. Traffic from the spur can follow the same route, but in the opposite direction. Figures 1D and 1E show arrangements which allow the rerouting of all traffic in response to a break in the trunk fibre. All signals for transmission to the broken trunk 102 in Figure 1D are dropped down spur 103 and communicated through a back-haul network to another spur for a branching unit as shown in Figure 1E, so that all signals to travel along the trunk fibre are routed around the fibre break.

In C.R. Giles and V.Mizrahi, IOOC-95, ThC2-1,pp 66-67, an experimental arrangement is shown including a simple add/drop multiplexer in which the add/drop wavelength can be changed. An add/drop multiplexer of this general type is shown in Figure 15. The signal path, which links a first optical circulator 901 at which a signal may be dropped and a second optical circulator 902 at which a signal may be added, goes into a first 1x2 optical switch 903 and out from a second 1x2 optical switch 904. The two optical switches are linked by a first path with a Bragg grating 905 to reflect light at λ_1 and also by a second path with a Bragg grating 906 to reflect light at λ_2, with the result that the add/drop wavelength of the multiplexer can be switched between λ_1 and λ_2: the connection to ports of the circulators is such that only signals of the carrier wavelengths reflected by the Bragg grating on the chosen

signal path will be added or dropped. This document does not however provide or suggest a full solution to the problem of constructing rerouting mechanisms for use in branching units of a fibre optic network to achieve the functionality of Figures 1B to 1E.

There is thus a need to provide simple and economical switching mechanisms to achieve signal rerouting with the functionalities indicated in Figures 1B to 1E. Generally, there is a need to provide simple and reliable switching for branching units of a fibre optic network.

Accordingly, the invention provides a branching unit for a fibre optic network adapted to carry signals at a plurality of predetermined carrier wavelengths, comprising one or more inputs for receiving signals either from one or more trunk fibres of the network or from spur fibres for adding signals from spur stations of the network, one or more outputs for outputting signals either to one or more trunk fibres of the network or to spur fibres for dropping signals to spur stations of the network, and an add/drop multiplexer and switching means to provide two or more different routings of signals between said inputs and said outputs.

In one advantageous form, said switching means is adapted to provide alternative signal routings such that signals at one or more predetermined carrier wavelengths entering the branching unit at one input are directed in said alternative signal routings to alternative outputs of the branching unit. In another advantageous form, said switching means is adapted to provide a normal signal routing and an alternative signal routing, such that in said alternative signal routing, signals are rerouted from one or more designated outputs of the branching unit to one or more other outputs of the branching unit.

In certain preferred embodiments, said switching means comprises one or more switching elements having a first state in which signals pass directly therethrough and a second state in which signals are diverted around a loop path with one or more wavelength routing components thereon. At least one of said switching elements may be provided within said add/drop multiplexer: for at least one of said switching elements the add/drop multiplexer may be provided within the loop path.

Advantageously, the switching means comprises a prerouting switch network connected between inputs and outputs of said add/drop multiplexer and said inputs and outputs of the branching unit to enable rerouting of signals away from one or more of the branching unit outputs. Preferably, said signals rerouted away from the one or more of the branching unit outputs do not pass through the add/drop multiplexer. It is preferred that said prerouting switch network comprises a plurality of 2x2 optical switches, especially fused fibre switches comprising a fibre optic coupler in which the switching is accomplished by bending of the coupler fibres.

The invention further provides a branching unit for a fibre optic network adapted to carry signals at a plurality of predetermined carrier wavelengths, comprising one or more inputs for receiving signals from fibres of the network, one or more outputs for outputting signals to fibres of the network, and an add/drop multiplexer to route signals between said one or more inputs and said one or more outputs and switching means comprising one or more 2x2 optical switches to provide at least one alternative routing of signals between said one or more inputs and said one or more outputs.

In a further aspect, the invention provides a wavelength routing element for wavelength division multiplexing in a fibre optic network, comprising a linear array of switching segments defining a signal line between an input and an output of the wavelength routing element, and further comprising an input for a control signal, wherein each switching segment comprises: means for rerouting signals at one or more predetermined carrier wavelengths, and means for switching said signal rerouting means in or out of the signal line in response to a component of the control signal relating to said switching segment, such that signals at a chosen set of predetermined carrier wavelengths are reroutable according to the components of the control signal. Advantageously, there are N switching segments in said linear array, and for the Mth switching segment the signal rerouting means comprises a fibre Bragg grating for a carrier wavelength λ_M, so that components of the control signal are selectable to allow any carrier wavelength λ_M to be reflected or transmitted by the wavelength routing element. In this aspect, the invention further provides a multi-wavelength filter, and also an add/drop multiplexer, comprising such a wavelength routing element.

In a still further aspect, the invention provides a wavelength routing element for wavelength division multiplexing in a fibre optic network, comprising an input, an output and an input/output, means for selective routing of signals at predetermined wavelengths either from the input to the output or between the input/output and the input or output, and switching means for the selective signal routing means to switch the signal routing provided thereby, wherein the signal routing means is adapted such that a path for signals for routing from the input to the output irrespective of the state of the switching means is not even temporarily affected by any activation of the switching means.

Wavelength routing elements as described above may be used in add/drop multiplexers, and such add/drop multiplexers may be particularly adapted for use in branching units as indicated above.

In a further aspect, the invention provides a wavelength routing element, comprising an input, an output, and a switching element having a first state in which signals pass directly therethrough from the input to the output and a second state in which signals are diverted around a loop path with one or more wavelength routing components thereon.

The invention further provides a method of routing signals at a plurality of predetermined carrier wavelengths between stations of a fibre optic network, comprising directing said signals into branching units comprising both one or more passive add/drop multiplexers which provide a predetermined routing of signals according to carrier wavelength, and a switching network, and by operating the switching network so as to change the routing of signals within said branching units for one or more predetermined carrier wavelengths.

Such a method may be particularly adapted such that a signal path is provided within said branching units for signals for onward transmission along the fibre optic network which is not even temporarily affected by activation of any of the switching elements within one of said add/drop multiplexers.

Specific embodiments of the invention are described below, by way of example, particularly with reference to the accompanying drawings, of which:

Figures 1A to 1E show a desirable range of routing configurations for an exemplary branching unit of a fibre optic network;

Figures 2A and 2B show embodiments of switching elements for branching units according to embodiments of the invention;

Figure 3 shows an add/drop multiplexer for use in a branching unit according to an embodiment of the invention;

Figure 4 shows an add/drop multiplexer for use in a branching unit according to an embodiment of the invention;

Figures 5A and 5B show an add/drop multiplexer and a prerouting switching network for use in a branching unit according to a further embodiment of the invention;

Figures 6A, 6B and 6C show an add/drop multiplexer and a prerouting switching network for use in a branching unit according to a yet further embodiment of the invention;

Figures 7A, 7B, 7C and 7D show an add/drop multiplexer and alternative prerouting switching networks for use in a branching unit according to a still further embodiment of the invention;

Figures 8A and 8B show a switch configuration and a prerouting switching network for use in a branching unit according to another embodiment of the invention;

Figures 9A, 9B and 9C show wavelength routing means according to embodiments of a further aspect of the invention;

Figure 10 shows a wavelength separating filter adapted to employ the wavelength routing means of Figure 9; and

Figure 11 shows an add/drop multiplexer adapted to employ the wavelength routing means of Figure 9.

Figure 12 shows a first embodiment of an add/drop multiplexer comprising wavelength routing means according to a still further aspect of the invention;

Figure 13 shows a second embodiment of an add/drop multiplexer comprising wavelength routing means according to said still further aspect of the invention;

Figure 14 shows a third embodiment of an add/drop multiplexer comprising wavelength routing means according to said still further aspect of the invention; and

Figure 15 shows a prior art switchable add/drop multiplexer.

Figures 2A and 2B show embodiments of switching elements for branching units according to embodiments of the invention. Central to both embodiments is a 2x2 optical cross point switch 81. The switch 81 has two states, one in which signals pass straight through between corresponding points (82 with 84, and 83 with 85), and a second in which signals pass

between crossed points (82 with 85, and 83 with 84). The switching elements as a whole are configured to have a first state in which signals pass directly therethrough, and a second state in which signals are diverted around a loop 86 with one or more optical elements 88 thereon. In Figure 2A, when 2x2 switch 81 is set crossed, a signal will pass straight through between points 82 and 85, but when 2x2 switch 81 is set uncrossed, signals will be diverted around loop 86. The result is that in the crossed state, this switching element will allow all signals straight through, but in the uncrossed, or "straight through" state, signals at the carrier wavelength λ_1 will be reflected back by optical component 88, in this case a notch reflection filter (preferably a fibre Bragg grating) at λ_1. The switching element is symmetrical, so this behaviour applies both to signals entering at point 82 and at point 85. Similarly, the switching element in the Figure 2B embodiment will in the crossed state reflect signals at λ_1 only. In the straight through state, signals will be diverted around loop 86 and signals at carrier wavelength λ_2 will also be reflected by fibre Bragg grating 88. Signals to activate the switches may be provided by electrical control signals or any other appropriate conventional means.

A particularly advantageous form of 2x2 switch is a mechanically actuated fused fibre switch, such as those produced by OptiVideo Corporation of Boulder, Colorado, USA. These switches are optomechanical devices. They comprise a fibre optic coupler consisting of a pair of fibres fused together (such fused pairs are manufactured by Corning Inc.). Two inputs and outputs are provided, one of each on each fibre. In an unstressed state, signals pass directly along between each fibre between the respective input and output and do not pass between fibres. However, when mechanical force is applied to the coupler to provide a precisely determined degree of bending (this can be achieved with an electromechanical

actuator), the characteristic of the coupler changes, and signals will pass substantially entirely from the input on one fibre to the output on the other fibre. Such a switch does not require making/breaking the fibre paths - there is no point where no optical path exists through the switch because fibres forming part of the path are not in contact with each other, as in conventional make/break switches. Such a switch is particularly appropriate in the context of the present invention, as it offers low loss and high repeatability.

Such switching elements can be used in a branching unit for a fibre optic network adapted to carry signals at a plurality of predetermined carrier wavelengths, as is shown in Figure 3. The branching unit comprises an input 1 for receiving signals from a trunk fibre, an output 2 for outputting signals to a trunk fibre, an input 3 for receiving signals from a spur fibre (add fibre) connected to a spur station of the network, and an output 4 for outputting signals to a spur fibre 4 (drop fibre). Between and connecting these inputs and outputs is an add/drop multiplexer, in this case an essentially passive add/drop multiplexer comprising three-port optical circulators 13, 14 and a fibre connection between them. Each optical circulator circulates substantially all of a signal received at one port out through the next port in sequence (as shown by the arrow). A switching means is provided, in this case consisting of a switching element within the add/drop multiplexer (situated on the fibre connection), to provide two different routings of signals between said inputs and said outputs. The switching element is essentially as that shown in Figure 2A, and comprises a 2x2 switch 11 and a loop 16 with a fibre Bragg grating 18 thereon. In this case, if switch 11 is in the uncrossed state, signals will pass directly between trunk input 1 and trunk output 2, and between spur input 3 and spur output 4, except at the carrier wavelengths reflected by fibre Bragg grating (or gratings) 18: as can be seen by tracking signals through optical circulators 13 and 14, signals

at these carrier wavelengths pass from trunk input 1 to spur output 4 and from spur input 3 to trunk output 2 respectively. However, if switch 11 is switched to the crossed position, loop 16 is taken out of circuit, and all signals pass directly from trunk input 1 to trunk output 2 and from spur input 3 to spur output 4. It should be noted that this arrangement does not allow light to circulate in the reverse direction if conventional three port circulators are employed (in which light entering at the third port is absorbed and not circulated to the first port of the circulator).

The arrangement of Figure 3 is thus appropriate to the functionality illustrated in Figure 1C, of particular assistance if the fibre connection to the spur station is broken. In such a circumstance, it is advantageous to route signals away from a designated output of the branching unit (in this case the spur output) where such signals would otherwise be lost through a fibre break. Other branching units of the network can then be reconfigured so that the signals for the relevant spur stations are dropped from the trunk elsewhere and routed back to their intended destination by a back-haul network, for example. However, by using instead of a Figure 2A switching element a Figure 2B switching element, a branching unit could be provided that was switchable so as to route one set of wavelengths between branch and spur when the loop was out of circuit, and an additional set of wavelengths between branch and spur when the loop was in circuit - such an arrangement would be of the type illustrated in Figure 1B, and would be of benefit when it was desired to increase the signal capacity of the spur.

It is of course desirable also to provide the functionality of Figures 1D and 1E, so that breaks in the trunk fibres can be allowed for by directing signals away from designated outputs

which are outputs to trunk fibres in a common section of trunk fibre cable. Such an arrangement is shown in Figure 4.

The Figure 4 arrangement is essentially similar to that of Figure 3, but a further switching element 21 has been arranged for interposition between trunk input 1, spur output 4, and optical circulator 13. Similarly, a still further switching element 22 has been arranged for interposition between spur input 3, trunk output 2, and optical circulator 14. Switching elements 21 and 22 are of essentially the same construction as that shown in Figure 2A, and the arrangement is in each case such that the add/drop multiplexer is effectively in the loop. If both switching elements 21 and 22 are in the uncrossed position, the routing achieved by the Figure 4 branching unit will be exactly that achieved by the Figure 3 branching unit. However, if either switching element is crossed, the routing is changed fundamentally. For example, if switching element 21 is crossed, signals from trunk input 1 pass directly to spur output 4: this arrangement is appropriate if the branch output side is broken (Figure 1D case). Likewise, if switching element 22 is crossed, all signals from spur input 3 pass directly out to branch output 2, which will be appropriate if the branch input side is broken (Figure 1E case). In both these cases, modifications will of course be required at other points in the network to enable the signals to be routed through alternate paths to the intended destination. More than one of the Figure 4, or the Figure 3, arrangements can be combined together in a multiple branching unit for the case of a network with a plurality of trunk or spur fibres.

An alternative way of achieving an active functionality, and more particularly of providing a branching unit with active functionality based upon a passive add/drop multiplexer, is by

providing a prerouting switch network connected between inputs and outputs of the branching unit to enable rerouting of signals away from one or more of the branching unit outputs. An embodiment of the invention employing this approach is described below with reference to Figures 5A and 5B.

Figure 5A shows a passive add/drop multiplexer with a particularly useful functionality. An add/drop multiplexer with this functionality can be constructed from a Mach-Zehnder interferometer comprising two matched 50:50 fibre optic couplers, linked by two matched paths having one or more fibre Bragg gratings thereon - such a Mach-Zehnder interferometer is discussed in Johnson et al, Electronics Letters, Vol. 23, pp 668-9, 1987, and add/drop multiplexers using such interferometers are discussed in the applicant's copending International Patent Application entitled "Add/drop Multiplexer" and referred to above. The add/drop multiplexer 30 (add/drop multiplexers of this type are termed below as MZ-ADMs, for Mach-Zehnder Add/Drop Multiplexer) has a first input and a first output (here labelled T_i for trunk input and T_o for trunk output respectively) and a second input and a second output (here labelled A for spur fibre add and D for spur fibre drop respectively). (c) indicates that these designations apply to the MZ-ADM component, for reasons indicated below. For a first set of carrier wavelengths (those passing straight along the trunk), signals are routed from first input to first output and from second input to second output. However, for a second set of carrier wavelengths (those to be dropped to and added from the spur), signals are routed from the first input to second output and from second input to first output.

The MZ-ADM 30 shown in Figure 5A is thus fundamental to the branching unit of this embodiment. The other critical aspect is the prerouting switch network 36, illustrated in

Figure 5B. This comprises here three 2x2 switches 31,32,33 of the type discussed above, though it will be appreciated that the man skilled in the art could achieve the same functionality through other switch arrangements, for example an appropriate combination of 1x2 switches. In Figure 5B, the same convention is used to label the connection of signals as is shown in Figure 5A: there is however a difference in that certain points are additionally labelled (b) rather than (c). Points labelled (b) are connected to the inputs or outputs 1,2,3.4 of the branching unit itself: for example, T_i(b) is connected directly to the trunk fibre input 1. Points labelled (c) are as before connected to the appropriate port of MZ-ADM 30: for example, T_i(c) emerging from switching element 33 in Figure 5B is the same position as T_i(c) in Figure 5A, and shows that this port of switching element 33 is connected directly to the relevant port of MZ-ADM 30.

The resulting active functionality of the branching unit resulting is illustrated in Table 1 below. Route options are indicated with regard to the relevant one of Figures 1A to 1E, and the position of each switch is indicated by S (straight through), C (crossed), or - (undetermined - not relevant to routing).

Route Option	Routing	31	32	33
FIG. 1A	Normal add/drop	S	S	S
FIG. 1C	Ti→To	S	S	C
FIG. 1D	Ti→D	C	-	-
FIG. 1E	A→To	-	C	S

TABLE 1

As can be seen, if all switches are in the straight through state a "normal" routing is achieved, and all signals pass directly between the relevant branching unit input (or output) and the relevant MZ-ADM input (or output). Crossing of switch 31 causes the trunk input signal to be dropped directly into the spur drop fibre without even passing through the MZ-ADM, thus achieving the Figure 1D functionality. In similar fashion, appropriate switching of switches 31, 32 and 33 can provide the routings of Figures 1C and 1E without any signals passing through the MZ-ADM 30.

As is indicated above, this active functionality can be achieved with a different switching arrangement (for example, six 1x2 switches), but the 2x2 arrangement shown is particularly advantageous as it requires only a small number of relatively cheap and simple components.

A further form of passive add/drop multiplexer which forms the basis of another embodiment of the invention is shown in Figure 6A. Such add/drop multiplexers may be provided by, for example, appropriate combinations of optical circulators and fibre Bragg gratings. Such an arrangement, further described in the applicant's copending International Patent Application entitled "Add/drop Multiplexer" and referred to above: one example employing a five port optical circulator is shown in Figure 6C. This add/drop multiplexer has a first input and a first output (here labelled $T1_i$ for first trunk input and $T1_o$ for second trunk output respectively - two of these add/drop multiplexers are required for use with a pair of trunk fibres carrying signals in opposite directions) and also an input/output spur corresponding respectively to an input 1, an output 2, and an input/output 5 of a branching unit. Such a design is appropriate for use with unrepeatered spur cables. In similar fashion to the MZ-

ADM, for a first set of carrier wavelengths signals from the first input are routed to the first output, and for a second set of carrier wavelengths signals from the first input are routed to the input/output spur and signals from the input/output spur are routed to the first output.

The appropriate prerouting network 46 to achieve the functionalities of Figures 1A, 1C, 1D and 1E for such an add/drop multiplexer 40 are shown in Figure 6B, in which the same naming convention is used as is used with respect to Figure 5B. The switch configurations necessary to provide all these functionalities are shown in Table 2 below.

Route Option	Routing	41	42	43
FIG. 1A	Normal add/drop	S	S	S
FIG. 1C	T1i→T1o	C	S	-
FIG. 1D	T1i→B1(drop)	-	C	S
FIG. 1E	B1(add)→T1o	-	S	C

TABLE 2

S, C and - have the same meaning in Table 2 as they did in Table 1. Again, it can be seen that the functionalities of Figures 1C to 1E can be achieved without the passage of any of the signals into the add/drop multiplexer 40. Using this arrangement, only six 2x2 switches are required for a branching unit for a trunk fibre pair - if 1x2 switches were used, twelve switches would be required.

A passive add/drop multiplexer 50 which is in itself adapted for use with a trunk fibre pair

and add and drop fibres to a spur station is depicted in Figure 7A. Such add/drop multiplexers are discussed, for example, in the applicant's copending International Patent Application entitled "Add/drop Multiplexer" referred to above, and an example is shown in Figure 7D. There are two trunk fibre inputs ($T1_i$ and $T2_i$) and two trunk outputs ($T1_o$ and $T2_o$), there being for each trunk fibre an input/output pair comprising an input and an output (e.g., $T1_i$ and $T1_o$). There is also provided a spur input A and a spur output D. The signals are routed according to carrier wavelength - signals arriving at a trunk fibre input are routed either to the trunk fibre output of that input/output pair or else to the spur output D, and signals arriving from spur input A are routed to an appropriate one of the trunk fibre outputs. This design may readily be expanded by addition of further trunk fibres (with consequent addition of a trunk fibre input and a trunk fibre output in an input/output pair for each additional trunk fibre).

A prerouting network for a branching unit employing add/drop multiplexer 50 in accordance with an embodiment of the invention is depicted in Figure 7B. The same labelling convention as used in previous Figures is adopted to indicate the connections between the prerouting switch network and the inputs 1,1' (trunk) 3 (spur) and outputs 2,2' (trunk) 4 (spur) of the branching unit itself and of the add/drop multiplexer 50 respectively. In the network of Figure 7B, six 2x2 switches 51-56 are employed. As previously, the switch configurations required to give the functionalities of the appropriate Figures of Figures 1A to 1E are shown in a table, here Table 3 below.

Route Option	Routing	51	52	53	54	55	56
1	Normal add/drop	S	S	S	S	S	S
3	T1i→T1o T2i→T2o	S	S	C	C	-	-
4	T1i→D A→T2o	S	C	S	-	C	S
5	T2i→D A→T1o	C	-	-	S	-	C

TABLE 3

Again, normal add/drop is achieved with all switches in the straight through position. Appropriate switching allows each of the Figure 1C to Figure 1E routings to be achieved. It is to be noted that the arrangement shown in Figure 7B can readily be scaled to a greater number of trunk fibres. A column of three switches (51, 53, 55; 52, 54, 56) is provided for each input/output pair: linking each column is a spur input line 57, passing here through switches 51 and 52, and a spur output line 58, passing through switches 55 and 56 in this case. The column comprising switches 51, 53 and 55 is, in itself, identical in function to the column comprising switches 52, 54 and 56, and it can readily be seen that the arrangement can be expanded to further trunk fibres by adding further columns as appropriate.

An alternative prerouting network with the same functionality as that shown in Figure 7B is

shown in Figure 7C. The labelling convention adopted in Figure 7C is the same adopted as that in Figure 7B and other earlier Figures. The Figure 7C prerouting network 66 employs twelve 1x2 switches, arrayed in pairs 61,62, each pair effectively functioning as a 1x3 switch. A table to illustrate the routing combinations is not provided, but it can be seen that appropriate switching combinations will provide all the routings shown in Table 3.

While use of 1x2 switches generally requires twice as many switches to be used as when 2x2 switches are used, it is to be noted that use of higher order switches (e.g. nxn with $n>2$) can reduce the number of switches required still further. Figure 8A illustrates a 4x4 switch. Such switches are available commercially from, for example JDS Fitel Inc., of Nepean, Ontario, Canada. There are four inputs (In1 to In4) and four outputs (Out1 to Out4), each set forming a cyclic sequence 1 to 4. Switch 71 is rotatable so that the inputs and outputs match with each other: any input can match with any output, but only such that all inputs and outputs are matched at any given time according to the cyclic sequence.

Figure 8B shows a prerouting switch network for a further embodiment of a branching unit according to an embodiment of the invention for use with add/drop multiplexer 40 of Figure 6A. The labelling convention shown is as before. No table is provided below, but it examination will indicate that bringing, in succession, the outputs 74, 75, 76 and 77 into communication with input 73 will lead to the Figure 1A state, the Figure 1E state, the Figure 1C state and the Figure 1D state.

Although use of higher order switches can lead to the use of fewer switches in total, the use of 2x2 switches as components is particularly advantageous and embodiments employing 2x2

switches are preferred. Several topologies are indicated in the aforementioned Figures which can be applied with, or around, passive wavelength division add/drop multiplexers to provide an active switched unit by the use of switch networks. In particular, 2x2 cross point fibre optic switches, advantageously provided in the form of fused fibre switches, can be used to provide all the functionalities indicated in and discussed above with reference to Figures 1A to 1E. Such switches can thus be used to provide in this way an all-fibre, low loss switching network in branching units according to the invention.

Figures 2A and 2B show simple switching elements, which allow a loop to be added to the signal circuit, the loop having one or more optical components as means for rerouting signals at predetermined carrier wavelengths - in the cases illustrated, these optical components are fibre Bragg gratings 88. A simple, sophisticated and versatile alternative form of switching element, or wavelength routing element, in accordance with an embodiment of a further aspect of the invention, is shown in Figure 9A.

Figure 9A shows a wavelength routing element for wavelength division multiplexing in a fibre optic network. It comprises a linear array 200 of switching segments 201, 202, 203. This linear array defines a signal line between an input 207 and an output 208 of the wavelength routing element. The wavelength routing element also has an input (not shown) for a control signal. Switching segment 201 comprises means for rerouting signals at one predetermined carrier wavelength. In this case, these means are fibre Bragg grating 211, which reflects signals at λ_1. This is on one of two paths 231, 232 between 1x2 optical switches 221 and 222. This switching segment also comprises, in the form of optical switches 221 and 222 and the paths 231 and 232 therebetween, means for switching the

signal rerouting means in or out of the signal line in response to a component of the control signal relating to that switching segment. Switches 221 and 222 are switchable between one position, in which signals are carried between the two along path 231, in which case fibre Bragg grating 211 is not in circuit, and a second position in which signals are carried between the switches along path 232, in which case fibre Bragg grating 211 is in circuit and signals at λ_1 are reflected by the switching segment (back in whichever direction they arrived from). Each switching segment is similar, but different fibre Bragg gratings (or other appropriate optical components) are provided for each switching segment so that the signals at a chosen set of predetermined carrier wavelengths are reroutable according to the components of the control signal.

The control signal may be provided in any way consistent with, say, provision of an on/off signal at each switching element. With appropriate construction of the switching element, it can then be placed in the first or second position accordingly.

An alternative embodiment which achieves the same functionality is shown in Figure 9B. Linear array 300 comprises a series of switching elements 301, 302, 303. Each switching element is essentially similar to the switching element shown in Figure 2A. For example, switching element 301 comprises 2x2 optical switch 321. If switch 321 is in the crossed position, signals pass directly through the switch between input 207 and the input to the next switching element 302. However, if switch 321 is in the straight through position, signals pass around a loop with fibre Bragg grating 311 thereon, so signals on the signal line at λ_1 are reflected at switching element 301. Again, optical components on the loop of each switching element are chosen so that a chosen set of predetermined carrier wavelengths are

rerouted according to the components of the control signal. This arrangement is advantageous in that only one switch is now required per grating.

Losses can be reduced by use of a further embodiment of the invention providing the same functionality. This embodiment is illustrated in Figure 9C, and provides a combination of features from the Figure 9A and the Figure 9B embodiments. Linear array 400 comprises N+1 optical switches and N gratings (or other optical components). An exemplary switching element comprises optical switches 421 and 422 (shown as 2x2, though the switches adjacent to input 207 and output 208 may be 1x2) and two paths 431 and 432 therebetween. Fibre Bragg grating 411 is located on path 432, and optical switch 421 is switchable so that either path 431 or path 432 is part of the signal line, with the result that the switching element will not, or will, reflect signals at carrier wavelength λ_1 respectively. It should be noted that in contrast to the Figure 9A and Figure 9B embodiments, the control signal component provided to a given switching element is not independent of the control signal components provided to other switching elements - whether the previous grating was selected or not selected for the signal line determines the switching state required to include the grating of a given switching element in the signal line.

The losses for the three configurations shown in Figures 9A to 9C are shown in Table 4 below. Losses of 0.3 dB are assumed for switches and fibre Bragg gratings, whereas losses for splices are neglected.

	1x2 switch BGR Components	Loss (dB)	2x2 switch BGR #1 Components	Loss (dB)	2x2 switch BGR #2 Components	Loss (dB)
Max. loss	16 SW - 8 FBG	7.2	16 SW - 8 FBG	7.2	9 SW - 8 FBG	5.1
Min. loss	16 SW - 0 FBG	4.8	8 SW - 0 FBG	2.4	9 SW - 0 FBG	2.7
Delta loss		2.4		4.8		2.4

TABLE 4

The losses indicated in Table 4 above are useful for comparison purposes, but actual device losses will depend on the properties of the components available. It can be seen that the Figure 9A embodiment has a high static loss, but relatively low differential losses. The Figure 9B embodiment has a lower minimum loss, but an equally high maximum loss: it thus has a significantly greater differential loss. The Figure 9C embodiment has a minimum loss only marginally greater than that of the Figure 9B embodiment (there is one additional switch), but has the same differential loss as the Figure 9A embodiment. The Figure 9C embodiment is thus likely to provide the most advantageous practical option, with less than 6 dB total loss and less than 3 dB differential loss for an eight wavelength router.

The arrangements shown in Figures 9A to 9C all involve N switching segments, each adapted to be switchable between reflection and transmission of a carrier wavelength λ_N, thus providing 2^N routing options. This form of wavelength routing element is particularly

preferred. N control lines, which may for example be provided by sending an N bit binary word, may be provided as the control signal input for the wavelength routing element - the wavelength routing element may thus be considered as a binary grating router, with the status of each switching element (or fibre Bragg grating) defining a binary word. This arrangement can provide a fully variable wavelength routing in very simple fashion with very low losses.

Such a wavelength routing element can form the key element of a wavelength separating filter, as is shown in Figure 10. Binary grating router 501, with control signals 502 input in the form of an N bit word or similar, is provided between a second port of three port circulator 503 and a trunk fibre output 512. Trunk fibre input 511 is connected to the first port of the circulator 503 and drop fibre 514 is connected to the third port of the circulator. Signals at wavelengths λ_N for which appropriate fibre Bragg gratings are provided in the signal line are input through trunk fibre input 511, circulated to binary grating router 501, which reflects them, and then further circulated out through drop fibre 514. Signals at wavelengths λ_N for which the appropriate fibre Bragg gratings are switched out of the signal line pass straight through the binary grating router 501 and out through the trunk fibre output 512.

Addition of a further three port optical circulator 504 leads to an add/drop multiplexer with a binary grating router within it. The add/drop multiplexer provided is that of Figure 3, with the switching element of Figure 2A replaced by that of (for example) Figure 9C. It can be seen that signals at λ_N not chosen in the control signal 502 pass directly between trunk input fibre 511 and trunk output fibre 512, and between add fibre 513 and drop fibre 514. By contrast, signals at λ_N selected in the control signal pass either from trunk input fibre 511 to

drop fibre 514 or from add fibre 513 to trunk output fibre 512.

This arrangement allows for simple and sophisticated reprogramming of a branching unit to provide, for example, the functionality of Figure 1B. It is particularly useful in cases where bi-directional traffic to and from a location is required (as is usually the case).

A potential disadvantage is found in the wavelength routing elements of Figures 2 and 9, and in add/drop multiplexers constructed therefrom. This disadvantage is that the switching operation will take a finite time, so that traffic on channels to pass straight through a multiplexer will be momentarily interrupted during the switching process as there will be a brief period during which there is no operative signal path. Even if by appropriate component choice one path could be made before the other was broken, it is unlikely that the path lengths would be exactly equal and traffic errors would still result due to path phase differences. This disadvantage applies equally to earlier attempts to provide wavelength routing with switched gratings.

An add/drop multiplexer adapted not to have this disadvantage is shown in Figure 12. The add/drop multiplexer comprises two wavelength routing elements 601 and 602. Each wavelength routing element has an input, an output, and a further connection point which may be used as either an input or an output, depending on the utilisation of the element - this connection point is here termed an input/output.

For wavelength routing element 601, the central element is a three-port optical circulator 611. The input to the element is at the first port of the circulator 611, and the output is

provided at the third port. The second port is connected to a signal routing means. The signal routing means comprises a signal reflecting section 612. This consists of a fibre connected to the second port of circulator 611 and having thereon a plurality of fibre Bragg gratings, each adapted to reflect a different carrier wavelength λ_1 to λ_{n-1}. The signal routing means also comprises a switchable part 613 by which the signal routing provided by the signal routing means can be altered. The switchable part comprises a switching means 631, here a 1x2 switch, and two alternative signal paths 632 and 633. One signal path terminates in a further fibre Bragg grating reflecting at λ_n, whereas the other terminates in the input/output of the wavelength routing element. This arrangement allows for selective routing of signals at λ_n between, in this case, either the input and the output or alternatively the input or output and the input/output: this is similar to the arrangement of Figure 10, which the wavelength routing element of Figure 12 resembles in certain aspects.

However, in this arrangement, the signal routing means is adapted such that a path for signals for routing from the input to the output irrespective of the state of the switching means is not affected, even temporarily, by any activation of the switching means. In the Figure 12 case, signals at λ_1 to λ_{n-1} are all intended to pass from the input to the output regardless of the state of the switching means. Any such signal will enter the circulator 611 through the first port, pass out through the second port into the signal reflecting part 612. The signal will then be reflected by the appropriate one of the fibre Bragg gratings, and will return to the second port of the circulator 611. It will then pass out through the third port of the circulator - the output. The signal does not enter a switched part 613 of the signal routing means, and is thus not even temporarily affected by any activation of the switching means 631.

As is shown in Figure 12, a particularly simple and effective form of add/drop circulator can be constructed from two such wavelength routing elements. Wavelength routing elements 601 and 602 are substantially identical - the only difference is in the use of the input/output. For element 601, the input/output is used as an output: adapted as a drop output 4 to a branch station. For element 602, the input/output is used as an input: an add input 3 from a branch station. The output of element 601 is provided through circulator 611 as the input for element 602. The input of element 601 is adapted for use as a trunk fibre input 1, whereas the output of element 602 is adapted for use as a trunk fibre output 2.

In operation, signals at carrier wavelengths λ_1 to λ_{n-1} enter from the trunk fibre at input 1, and pass through to the second port of circulator 611. They are then all reflected by the appropriate one of the fibre Bragg gratings in the signal reflecting part 612, and pass out of the third port of circulator 611 to the first port of circulator 621 of the second wavelength routing element 602. The signals are reflected at signal reflecting part 622 of the second wavelength routing element 602 and pass out of the third port of circulator 621 to the trunk fibre output. Thus, for the channels which are not involved in switching, the signal path is entirely unaffected as it does not include any switchable parts. This enables all trunk channels which are never to be added or dropped at this multiplexer to have the same optical path through the multiplexer at all times, thus allowing the multiplexer to be reconfigured without risk of trunk channel errors.

For signals at λ_n, there are two possibilities. In the case shown in Figure 12, both switches are at position A. In this configuration, signals at this wavelength are reflected by the switchable parts 613, 623 of the signal routing means in the same manner as for the other

wavelength channels λ_1 to λ_{n-1}, and accordingly pass through from trunk fibre input 1 to trunk fibre output 2. Drop output 4 and add input 3 are not connected in this configuration. The configuration is adapted for a branching unit having the "bypass" routing of Figure 1C - signals are neither dropped to nor added from a branch station. The normal Figure 1A case is provided when the two switches are at position B. Now a signal at λ_n input from the trunk fibre input 1 passes straight through signal routing means 612, as it is not reflected by any of the fibre Bragg gratings on the signal path, and is transmitted out through drop output 4. Likewise, a replacement signal at the same wavelength arriving through the add input 3 passes through all the gratings of signal routing means 622 and passes through circulator 621 to trunk fibre output 2. In this configuration, the signal at λ_n on the trunk fibre is dropped to a spur station and is replaced by a new signal at the same wavelength.

The skilled man will readily appreciate that different routing choices and combinations of wavelengths can readily be achieved by employing, for example, 1xn switches instead of 1x2 switches, or by having different combinations of gratings on the switch output.

Such an alternative possibility is shown in Figure 13, which illustrates a second embodiment of an add/drop multiplexer employing wavelength routing elements according to this aspect of the invention. Components unchanged from Figure 12 attract the same reference numbers, though it is to be noted that the fibre Bragg gratings in the signal reflecting parts 612, 622 cover only channels λ_1 to λ_{n-2}. The switchable parts 614 and 624 now comprise first and second 1x2 switches 641 and 642, adapted so that either of the alternative signal paths provided links the signal reflecting part 612 or 622 and the input/output of the appropriate wavelength routing element (and hence the add input 3 or the drop output 4 of the

multiplexer). The alternative signal paths 643 and 644 each have thereon a fibre Bragg grating, adapted to reflect λ_{n-1} and λ_n respectively. As can readily be seen, with the switching means in position A, signals at λ_n pass from trunk input 1 to trunk output 2 and signals at λ_{n-1} are dropped from trunk input 1 to drop output 4 and signals at the same wavelength may be replaced on trunk output 2 from add input 3. In position B, this is reversed - signals at λ_{n-1} remain on the trunk fibre whereas signals at λ_n are dropped and replaced. The shift of functionality is between the Figure 1A and the Figure 1B cases. Again, channels not to be added or dropped in any configuration of the add/drop multiplexer do not reach a switchable part of the multiplexer, and are entirely unaffected by the switching process.

A third embodiment of an add/drop multiplexer employing wavelength routing elements according to this aspect of the invention is shown in Figure 14. Where components are unchanged, the same reference numerals are used as in Figure 13. The switchable parts 615 and 616 differ from those shown previously in that the first of the alternative signal paths 653 comprises a fibre Bragg grating reflecting at λ_{n-1}, whereas the other of the alternative signal paths 654 has no fibre Bragg grating. In this arrangement, signals at λ_n are dropped from the trunk to drop output 4 and are replaced from add input 3 in either multiplexer configuration, but signals at λ_{n-1} pass straight along the trunk in configuration A when the main signal path includes signal path element 653, and are dropped to and replaced from the spur when the main signal path is in configuration B and hence includes signal path element 654. This arrangement allows for the addition of capacity to a spur station, again without any affect on signals which are not for any configuration to be dropped to and replaced from the spur.

It will be appreciated that alternative forms of switching are entirely consisted with this aspect of the invention - for example, the pair of 1 x 2 switches in the Figure 14 embodiment could be replaced by a 2 x 2 switch arrangement such as that shown in Figure 2A.

By use of such components employing switched elements within an appropriate passive add/drop multiplexer structure in branching units of a fibre optic system, signals for transmission through a branching unit along the trunk may be left unaffected, even momentarily, by a reconfiguration of the branching unit. Although signals dropped to or received from spur stations may be affected, signals passing the whole way along a fibre optic system from a first to a second terminal station may thus be entirely unaffected by a reconfiguration of the fibre optic system.

CLAIMS

1. A branching unit for a fibre optic network adapted to carry signals at a plurality of predetermined carrier wavelengths, comprising one or more inputs for receiving signals either from one or more trunk fibres of the network or from spur fibres for adding signals from spur stations of the network, one or more outputs for outputting signals either to one or more trunk fibres of the network or to spur fibres for dropping signals to spur stations of the network, and an add/drop multiplexer and switching means to provide two or more different routings of signals between said inputs and said outputs.

2. Branching unit as claimed in claim 1, wherein said switching means is adapted to provide alternative signal routings such that signals at one or more predetermined carrier wavelengths entering the branching unit at one input are directed in said alternative signal routings to alternative outputs of the branching unit.

3. Branching unit as claimed in claim 1, wherein said switching means is adapted to provide a normal signal routing and an alternative signal routing, such that in said alternative signal routing, all signals are rerouted from one or more designated outputs of the branching unit to one or more other outputs of the branching unit.

4. Branching unit as claimed in claim 3, wherein said one or more designated outputs are one or more outputs to a spur station of the network.

5. Branching unit as claimed in claim 3, wherein said one or more designated outputs are one or more outputs to trunk fibres in a common section of trunk fibre cable.

6. Branching unit as claimed in any preceding claim, wherein said switching means comprises means to reflect signals at predetermined carrier wavelengths.

7. Branching unit as claimed in claim 8, wherein said signal reflecting means are fibre Bragg gratings.

8. Branching unit as claimed in claim 6 or 7, wherein said switching means comprises one or more switching elements having a first state in which signals pass directly therethrough and a second state in which signals are diverted around a loop path with one or more signal reflecting means thereon.

9. Branching unit as claimed in claim 8, wherein each said switching element comprises a 2x2 optical switch.

10. Branching unit as claimed in claim 9, wherein said 2x2 optical switches each comprise a fused fibre coupler.

11. Branching unit as claimed in claim 10, each said 2x2 optical switch further comprising an electromechanical actuator adapted to strain fibres of the fused fibre coupler from a state in which signals pass directly along said fibres of the fused fibre coupler to a state in which signals pass between the fibres of the fused fibre coupler.

12. Branching unit as claimed in any of claims 8 to 11, wherein at least one of said switching elements is provided within said add/drop multiplexer.

13. Branching unit as claimed in claim 12, comprising an add/drop multiplexer having a first input, a first output, a second input and a second output, adapted such that for a first set of carrier wavelengths signals from the first input are routed to the first output and signals from the second input are routed to the second output, and such that for a second set of carrier wavelengths signals from the first input are routed to the second output and signals from the second input are routed to the first output, wherein the switching means comprises a first switching element within the add/drop multiplexer switchable to assign predetermined carrier wavelengths to the first set or the second set.

14. Branching unit as claimed in any of claims 8 to 13, wherein for at least one of said switching elements the add/drop multiplexer is provided within the loop path.

15. Branching unit as claimed in claim 14 where dependent on claim 13, wherein the switching means further comprises a second switching element in which the loop comprises the add/drop multiplexer through the first input and first output thereof, and a third switching element in which the loop comprises the add/drop multiplexer through the second input and second output thereof.

16. Branching unit as claimed in claim 3, wherein said switching means comprises a prerouting switch network connected between inputs and outputs of said add/drop

multiplexer and said inputs and outputs of the branching unit to enable rerouting of signals away from one or more of the branching unit outputs.

17. Branching unit as claimed in claim 16, wherein said signals rerouted away from the one or more of the branching unit outputs do not pass through the add/drop multiplexer.

18. Branching unit as claimed in claim 16 or claim 17 wherein the add/drop multiplexer has a first input, a first output, a second input and a second output, adapted such that for a first set of carrier wavelengths signals from the first input are routed to the first output and signals from the second input are routed to the second output, and such that for a second set of carrier wavelengths signals from the first input are routed to the second output and signals from the second input are routed to the first output.

19. Branching unit as claimed in claim 18, wherein the prerouting switch network comprises first, second and third switching elements, wherein said first switching element has a first input from the second output of the add/drop multiplexer, a second input from a first input to the branching unit, a first output to a second output of the branching unit and a second output to a first input of the third switching element, and wherein the second switching element has a first input from the first output of the add/drop multiplexer, a second input from a second input of the branching unit, a first output to a second input of the third branching unit and a second output to a second input of the add/drop multiplexer, and wherein the third switching element has a first output to a first input of the add/drop multiplexer and a second output to a first

output of the branching unit, wherein each of said switching elements is switchable between a first state in which signals from the first input pass to the first output and signals from the second input pass to the second output, and a second state in which signals from the first input pass to the second output and signals from the second input pass to the second output.

20. Branching unit as claimed in claim 16 or claim 17, wherein the add/drop multiplexer has a first input, a first output, and an input/output spur, adapted such that for a first set of carrier wavelengths signals from the first input are routed to the first output, and such that for a second set of carrier wavelengths signals from the first input are routed to the input/output spur and signals from the input/output spur are routed to the first output.

21. Branching unit as claimed in claim 20, wherein the prerouting switch network comprises first, second and third switching elements, wherein said first switching element has a first left-side connection to a first output of the branching unit, a second left-side connection to the first input to the add/drop multiplexer, a first right-side connection to a first left-side connection to the third switching element and a second right-side connection to a first right-side connection of the second switching element, and wherein the second switching element has a first left-side connection to a first input of the branching unit, a second left-side connection to the input/output spur of the add/drop multiplexer, and a second right-side connection to a second left-side connection of the third switching element, and wherein the third switching element has a first right-side connection to the first output of the add/drop multiplexer

and a second right-side connection to an input/output spur of the branching unit, wherein each of said switching elements is switchable between a first state in which signals pass between the first left-side connection and the first right-side connection and signals pass between the second left-side connection and the second right-side connection, and a second state in which signals pass between the first left-side connection and the second right-side connection and between the second left-side connection and the first right-side connection.

22. Branching unit as claimed in claim 16 or claim 17, wherein the add/drop multiplexer has a plurality of trunk fibre inputs, a plurality of trunk fibre outputs, there being defined for each trunk fibre an input/output pair comprising one of said plurality of trunk fibre inputs and one of said plurality of trunk fibre outputs, and a spur input and a spur output, the add/drop multiplexer being adapted such that signals are routed according to carrier wavelength from each said trunk fibre input to either the trunk fibre output of the input/output pair or the spur output, and from the spur input to determined ones of the plurality of trunk fibre outputs.

23. Branching unit as claimed in claim 22, wherein said prerouting network comprises for each one of said trunk fibres first, second, and third switching elements, wherein said first switching element has a first left side connection to a line receiving signals from a spur input of the branching unit, a second left side connection to a first left side connection of the second switching element, a first right side connection to a line for providing signals to the spur input of the add/drop multiplexer, and a second right side connection to a trunk fibre output of the branching unit for said one of the trunk

fibres, wherein the second switching element has a second left side connection to a first left side connection of the third switching element, a first right side connection to the trunk fibre output of the add/drop multiplexer for said one of the trunk fibres, and a second right side connection to a trunk fibre input of the branching unit for said one of the trunk fibres, and wherein the third switching element has a second left side connection to a line receiving signals from the spur output of the add/drop multiplexer, a first right side connection to the fibre input of the add/drop multiplexer for said one of the trunk fibres, and a second right side connection to a line for providing signals for a spur output of the branching unit for said one of the trunk fibres, wherein each of said switching elements is switchable between a first state in which signals pass between the first left-side connection and the first right-side connection and signals pass between the second left-side connection and the second right-side connection, and a second state in which signals pass between the first left-side connection and the second right-side connection and between the second left-side connection and the first right-side connection.

24. Branching unit as claimed in claim 16 or claim 17, wherein said prerouting switch network comprises a plurality of 2x2 optical switches.

25. Branching unit as claimed in claim 24, wherein said 2x2 optical switches each comprise a fused fibre coupler.

26. Branching unit as claimed in claim 25, each said 2x2 optical switch further comprising an electromechanical actuator adapted to strain fibres of the fused fibre

coupler from a state in which signals pass directly along said fibres of the fused fibre coupler to a state in which signals pass between the fibres of the fused fibre coupler.

27. Branching unit as claimed in claim 16 or claim 17, wherein said prerouting switch network comprises a plurality of 1x2 optical switches.

28. Branching unit as claimed in claim 16 or claim 17, wherein said prerouting switch network comprises one or more nxn switches, where n is an integer greater than two.

29. Branching unit as claimed in claim 28, wherein n is 4.

30. Branching unit as claimed in claim 29 , wherein the add/drop multiplexer has a first input, a first output, and an input/output spur, adapted such that for a first set of carrier wavelengths signals from the first input are routed to the first output, and such that for a second set of carrier wavelengths signals from the first input are routed to the input/output spur and signals from the input/output spur are routed to the first output, and wherein the prerouting switch network comprises a single 4x4 switch, having a first left side connection to a first input of the branching unit, a second left side connection to a first output of the branching unit, a third left side connection to an input/output spur of the branching unit, a fourth left side connection to the input/output spur of the add/drop multiplexer, a first right side connection to the first input of the add/drop multiplexer, a second right side connection to the first output of the add/drop multiplexer, and a third right side connection and a fourth right side connection connected to each other, said four left side connections forming a first

sequence of first, second, third, fourth left side connections and said four right side connections forming a second sequence of first, second, third and fourth right side connections, wherein said 4x4 switch has four positions, and for each position said first left side connection is in communication with a chosen one of said four right side connections, and wherein the remaining left side connections are each communicated with the right side connection having the relationship in the second sequence to the chosen one of the right side connections that said each remaining one of the left side connections has to the first left side connection.

31. Branching unit as claimed in any preceding claim, wherein said add/drop multiplexer consists of passive optical components.

32. A branching unit for a fibre optic network adapted to carry signals at a plurality of predetermined carrier wavelengths, comprising one or more inputs for receiving signals from fibres of the network, one or more outputs for outputting signals to fibres of the network, and an add/drop multiplexer to route signals between said one or more inputs and said one or more outputs and switching means comprising one or more 2x2 optical switches to provide at least one alternative routing of signals between said one or more inputs and said one or more outputs.

33. Branching unit as claimed in claim 32, wherein said 2x2 optical switches each comprise a fused fibre coupler.

34. Branching unit as claimed in claim 33, each said 2x2 optical switch further

comprising an electromechanical actuator adapted to strain fibres of the fused fibre coupler from a state in which signals pass directly along said fibres of the fused fibre coupler to a state in which signals pass between the fibres of the fused fibre coupler.

35. Branching unit as claimed in any of claims 32 to 34, wherein the add/drop multiplexer comprises passive optical components.

36. Branching unit as claimed in any of claims 32 to 35, wherein said switching means further comprises means to reflect signals at predetermined carrier wavelengths.

37. Branching unit as claimed in claim 36, wherein said signal reflecting means are fibre Bragg gratings.

38. Branching unit as claimed in claim 36 or 37, wherein said switching means comprises one or more switching elements each comprising a 2x2 optical switch connected to have a first state in which signals pass directly therethrough and a second state in which signals are diverted around a loop path with one or more signal reflecting means thereon.

39. Branching unit as claimed in claim 38, wherein at least one of said switching elements is provided within said add/drop multiplexer.

40. Branching unit as claimed in claim 38 or claim 39, wherein for at least one of said switching elements the add/drop multiplexer is provided within the loop path.

41. Branching unit as claimed in any of claims 32 to 34, wherein said switching means comprises a prerouting switch network connected between inputs and outputs of said add/drop multiplexer and said inputs and outputs of the branching unit to enable rerouting of signals away from one or more of the branching unit outputs.

42. Branching unit as claimed in claim 41, wherein said signals rerouted away from the one or more of the branching unit outputs do not pass through the add/drop multiplexer.

43. A wavelength routing element for wavelength division multiplexing in a fibre optic network, comprising a linear array of switching segments defining a signal line between an input and an output of the wavelength routing element, and further comprising an input for a control signal, wherein each switching segment comprises:

means for rerouting signals at one or more predetermined carrier wavelengths, and

means for switching said signal rerouting means in or out of the signal line in response to a component of the control signal relating to said switching segment,

such that signals at a chosen set of predetermined carrier wavelengths are reroutable according to the components of the control signal.

44. Wavelength routing element according to claim 43, wherein each said signal rerouting means comprises one or more fibre Bragg gratings.

45. Wavelength routing element according to claim 43 or claim 44, wherein each switching segment comprises a first 1x2 optical switch, a second 1x2 optical switch, a first path between said optical switches, and a second path between said optical switches having said rerouting means thereon, wherein said first and second switches are switchable in response to the control signal component between a first state in which the signal line comprises the first path and not the second path and a second state in which the signal line comprises the second path and not the first path.

46. Wavelength routing element according to claim 43 or claim 44, wherein each switching segment comprises a 2x2 optical switch with a first left side connection to a first part of the signal line, a first right side connection to a second part of the signal line, and a loop path between a second left side connection and a second right side connection of the optical switch, the loop path having said rerouting means thereon, wherein said optical switch is switchable in accordance with the control signal component between a first state in which the first left side connection is connected directly to the first right side connection through the switch and a second state in which the first left side connection is connected to the first right side connection through the loop path.

47. Wavelength routing element according to claim 43 or claim 44, wherein each switching segment comprises a first 2x2 optical switch, a second 2x2 optical switch, a first path between said optical switches, and a second path between said optical switches with said rerouting means thereon, wherein said first 2x2 optical switch is switchable in accordance with the control signal between a first state in which the

signal line comprises the first path and not the second path and a second state in which the signal line comprises the second path and not the first path. and wherein the second 2x2 optical switch of one switching segment is the first 2x2 optical switch of a next switching segment along the linear array.

48. Wavelength routing element as claimed in claim 46 or 47, wherein said 2x2 optical switches each comprise a fused fibre coupler.

49. Wavelength routing element as claimed in claim 48, each said 2x2 optical switch further comprising an electromechanical actuator adapted to strain fibres of the fused fibre coupler from a state in which signals pass directly along said fibres of the fused fibre coupler to a state in which signals pass between the fibres of the fused fibre coupler.

50. Wavelength routing element according to any of claims 43 to 49, wherein there are N switching segments in said linear array, and wherein for the Mth switching segment the signal rerouting means comprises a fibre Bragg grating for a carrier wavelength λ_M, so that components of the control signal are selectable to allow any carrier wavelength λ_M to be reflected or transmitted by the wavelength routing element.

51. A multi-wavelength filter comprising a wavelength routing element as claimed in any of claims 43 to 50.

52. Multi-wavelength filter as claimed in claim 51, comprising a three port optical

circulator, wherein a first input is connected to a first port of the optical circulator, a first output is connected to a third port of the optical circulator, and the input of the wavelength routing element is connected to the second port of the optical circulator and the output of the wavelength routing element is connected to a second output.

53. An add/drop multiplexer comprising a wavelength routing element as claimed in any of claims 43 to 50.

54. Add/drop multiplexer as claimed in claim 53, comprising a first three port circulator and a second three port circulator, wherein a first input is connected to a first port of the first circulator, a second input is connected to a first port of the second circulator, a first output is connected to a third port of the second circulator, a second output is connected to a third port of the first circulator, the input of the wavelength routing element is connected to the second port of the first circulator and the output of the wavelength routing element is connected to the second port of the second circulator.

55. A wavelength routing element for wavelength division multiplexing in a fibre optic network, comprising an input, an output and an input/output, means for selective routing of signals at predetermined wavelengths either from the input to the output or between the input/output and the input or output, and switching means for the selective signal routing means to switch the signal routing provided thereby, wherein the signal routing means is adapted such that a path for signals for routing from the input to the output irrespective of the state of the switching means is not even

temporarily affected by any activation of the switching means.

56. A wavelength routing element as claimed in claim 55, wherein the signal routing means comprises a signal reflecting section to reflect signals at predetermined carrier wavelengths for transmission from the input to the output irrespective of the state of the switching means so that such signals do not enter a switched part of the signal routing means.

57. A wavelength routing element as claimed in claim 56, wherein said signal reflecting section comprises one or more fibre Bragg gratings.

58. A wavelength routing element as claimed in claim 57, comprising a three-port optical circulator and a plurality of fibre Bragg gratings, wherein the input is provided to the first port of the circulator, the output is provided from the third port of the circulator, and the second port of the circulator is connected to the signal routing means, the signal routing means comprising a signal reflecting section connected to the second port of the circulator and comprising one or more fibre Bragg gratings of said plurality to reflect signals at one or more predetermined carrier wavelengths, and the signal routing means further comprising a part switchable by the switching means between two or more alternative signal paths for connection to the signal reflecting section, at least one of said alternative signal paths comprising one or more fibre Bragg gratings of said plurality to reflect signals at one or more different predetermined carrier wavelengths, and at least one of said alternative signal paths is adapted for connection to the input/output.

59. A wavelength routing element as claimed in claim 58, wherein the input/output is connectable to all the alternative signal paths.

60. A wavelength routing element as claimed in claim 58, wherein the input/output is not connectable to all the alternative signal paths, and wherein the alternative signal paths not connectable to the input/output are adapted to reflect all carrier wavelengths for provision at the input.

61. An add/drop multiplexer comprising one or more wavelength routing elements as claimed in any of claims 55 to 60.

62. An add/drop multiplexer as claimed in claim 61, comprising first and second wavelength routing elements, wherein a first multiplexer input is the input of the first wavelength routing element, a first multiplexer output is the output of the second wavelength routing element, a second multiplexer input is the input/output of the second wavelength routing element, and a second multiplexer output is the input/output of the first wavelength routing element, and wherein the output of the first wavelength routing element is connected to the input of the second wavelength routing element.

63. An add/drop multiplexer as claimed in claim 62, wherein the alternative signal paths of the first and second wavelength routing element are substantially identical, and wherein the switching means of the first and second wavelength routing elements are connected such that substantially identical ones of the alternative signal paths are

adapted to connect to the signal reflecting sections for any switching state of the switching means.

64. Branching unit as claimed in claim 1 or claim 2 comprising an add/drop multiplexer as claimed in any of claims 53, 54 or 61 to 63.

65. A wavelength routing element, comprising an input, an output, and a switching element having a first state in which signals pass directly therethrough from the input to the output and a second state in which signals are diverted around a loop path with one or more wavelength routing components thereon.

66. Wavelength routing element as claimed in claim 65, wherein said one or more wavelength routing components comprise means to reflect signals at predetermined carrier wavelengths.

67. Wavelength routing element as claimed in claim 66, wherein said signal reflecting means are fibre Bragg gratings.

68. Wavelength routing element as claimed in any of claims 65 to 67, wherein the switching element comprises a 2x2 optical switch.

69. Wavelength routing element as claimed in claim 68, wherein said 2x2 optical switch comprises a fused fibre coupler.

70. Wavelength routing element as claimed in claim 69, wherein said 2x2 optical switch further comprises an electromechanical actuator adapted to strain fibres of the fused fibre coupler from a state in which signals pass directly along said fibres of the fused fibre coupler to a state in which signals pass between the fibres of the fused fibre coupler.

71. A fibre optic network, comprising two terminal stations, two or more trunk fibres for connecting said two terminal stations, one or more branch stations each connected by a spur fibre to a fibre trunk defined by said two or more trunk fibres, and one or more branching units as claimed in any of claims 1 to 41 or claim 64 on the fibre trunk each to allow exchange of traffic signals between said trunk fibres and one or more of said spur fibres.

72. A fibre optic network as claimed in claim 71 and adapted such that a substantial part of said fibre trunk comprises submarine cable, and in that said one or more branching units are adapted for submarine use.

73. A method of routing signals at a plurality of predetermined carrier wavelengths between stations of a fibre optic network, comprising directing said signals into branching units comprising both one or more passive add/drop multiplexers which provide a predetermined routing of signals according to carrier wavelength and a switching network, and by operating the switching network so as to change the routing of signals within said branching units for one or more predetermined carrier wavelengths.

74. Method of routing signals according to claim 73, wherein said switching network comprises for a branching unit a prerouting switch network connected between inputs and outputs of said add/drop multiplexer or multiplexers and said inputs and outputs of the branching unit, whereby on operation of the prerouting switch network selected ones of said signals are rerouted so that they do not pass through the add/drop multiplexer or multiplexers.

75. Method of routing signals according to claim 73 or claim 74, wherein said switching network comprises one or more switching elements within one or more of said one or more add/drop multiplexers whereby on activation of said one or more switching elements the functionality of an add/drop multiplexer is changed.

76. Method of routing signals according to claim 75 wherein a signal path within said add/drop multiplexer or multiplexers for signals at one or more predetermined carrier wavelengths for onward transmission along the fibre optic network is provided which is not even temporarily affected by activation of any of said one or more switching elements.

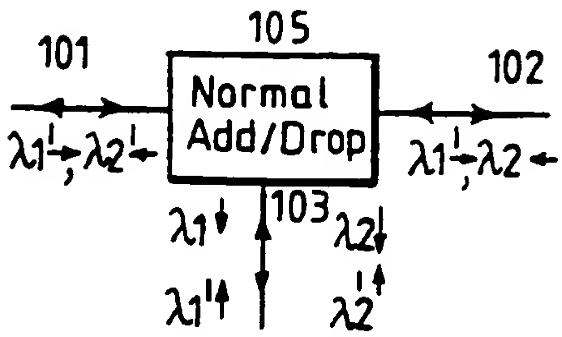


FIG.1A.

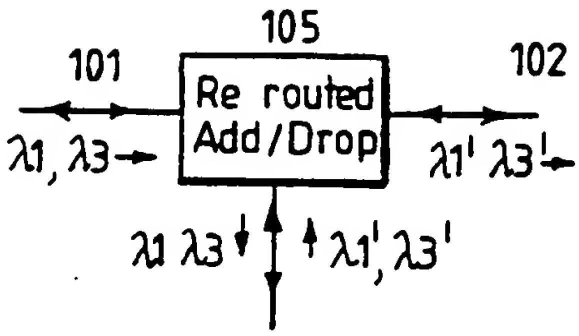


FIG.1B.

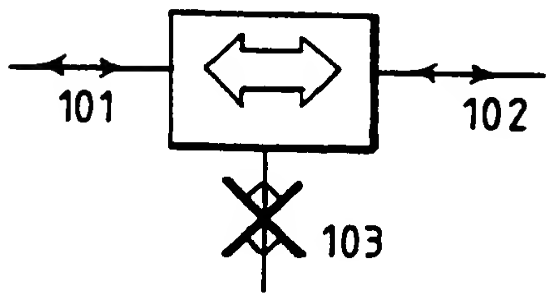


FIG.1C.

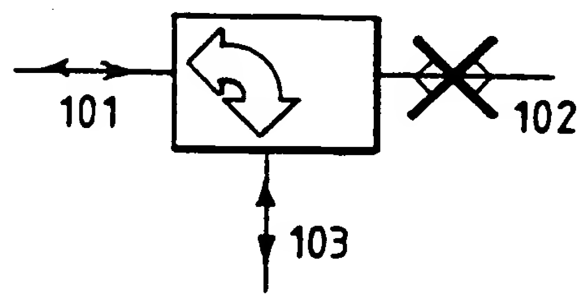


FIG.1D.

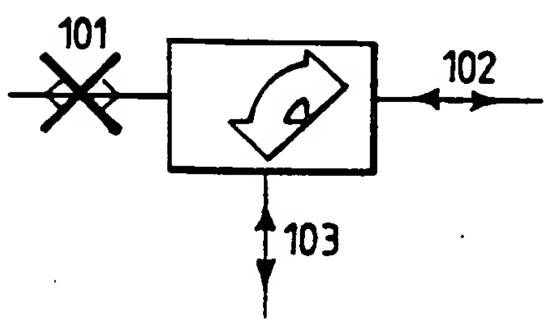


FIG.1E.

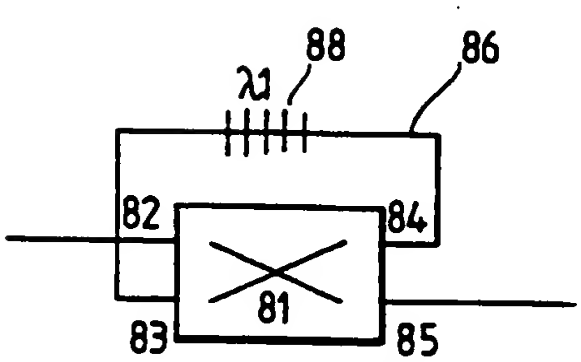


FIG.2A.

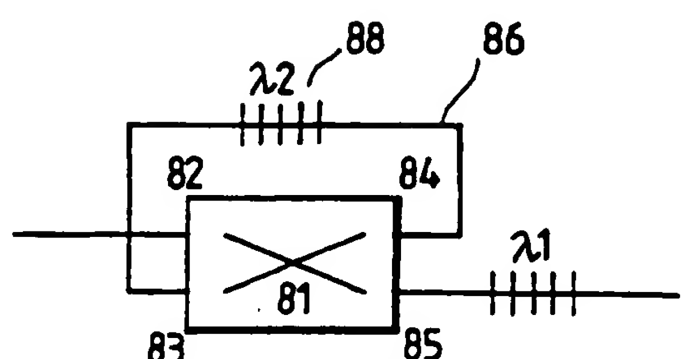


FIG.2B.

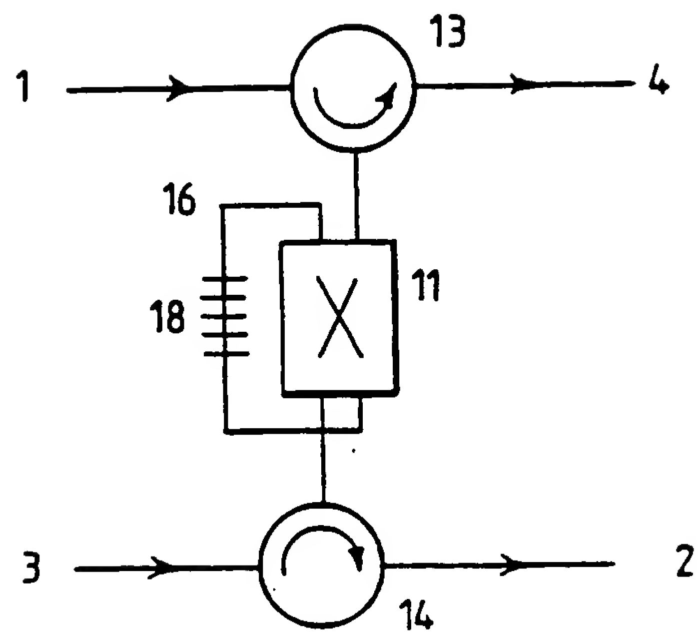


FIG. 3.

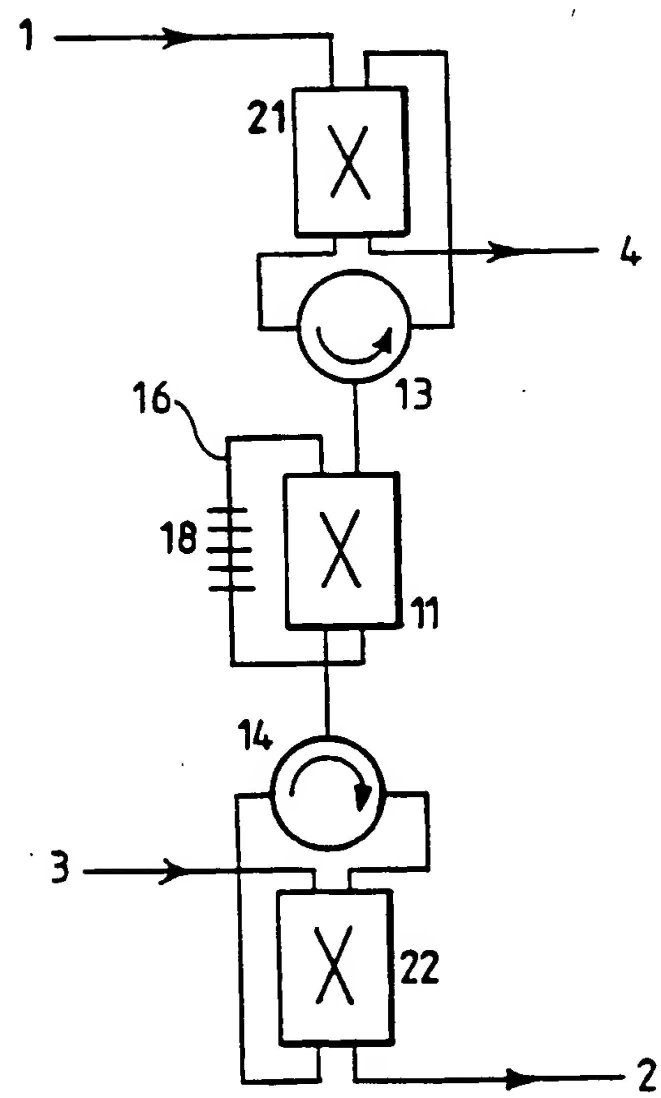


FIG. 4.

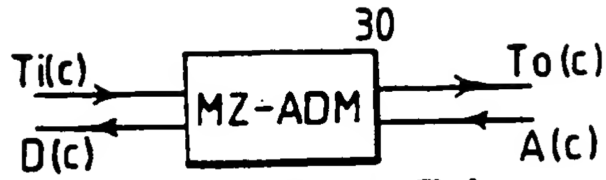


FIG.5A.

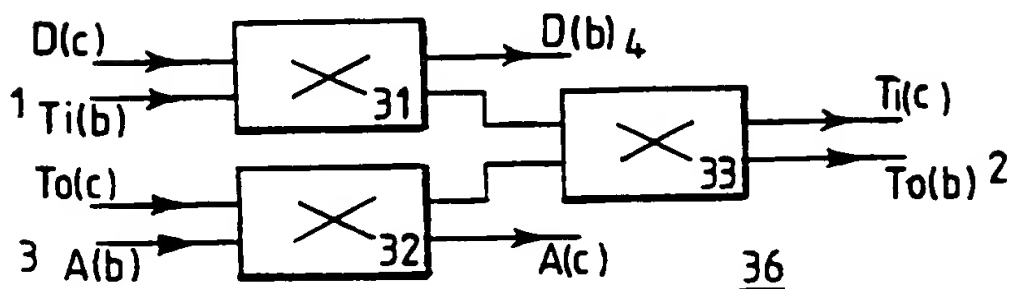


FIG.5B.

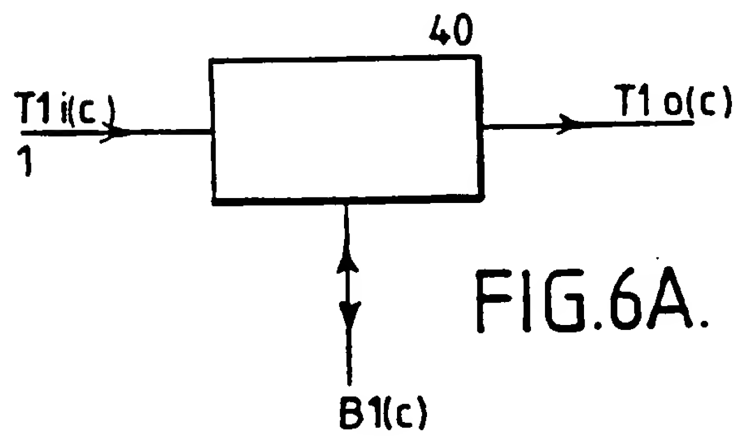


FIG.6A.

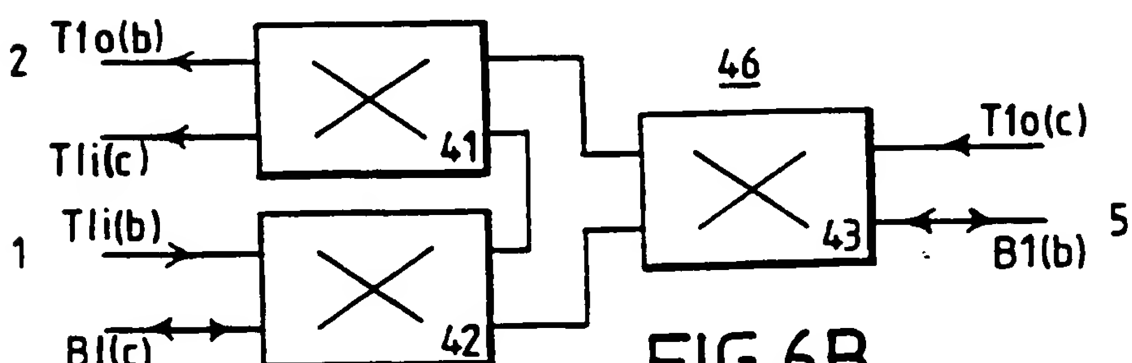
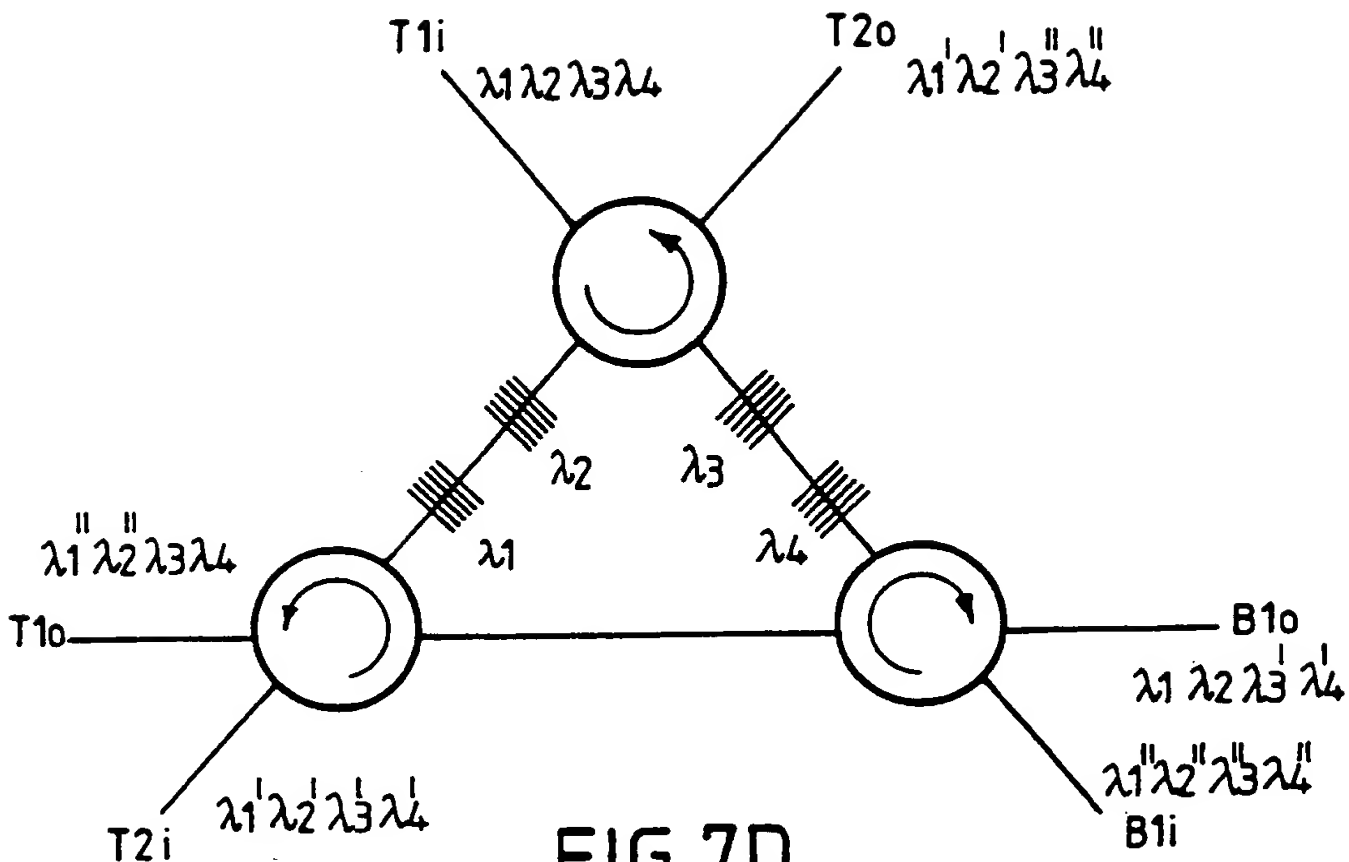


FIG.6B.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T2o
λ1'λ2'λ3''λ4''
λ2
λ3
λ1
λ4
λ1''λ2''λ3λ4
T1o
B1o
λ1 λ2 λ3' λ4'
λ1''λ2''λ3''λ4''
B1i
T2i
λ1'λ2'λ3'λ4'

FIG.7D.

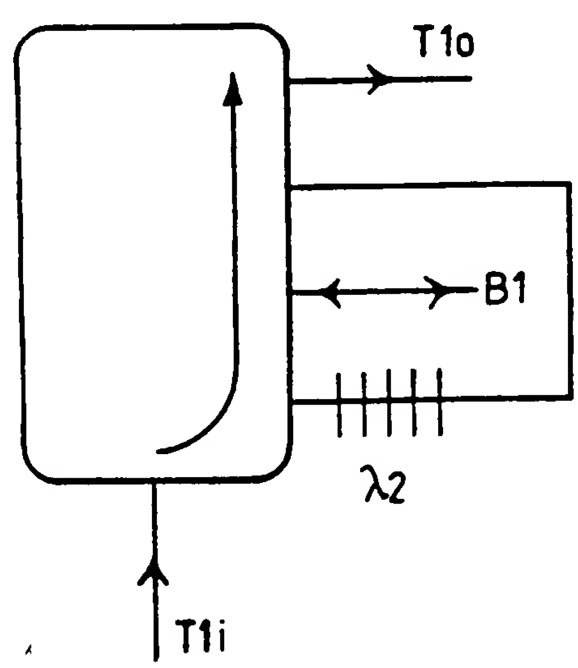

T1o
B1
λ2
T1i

FIG.6C.

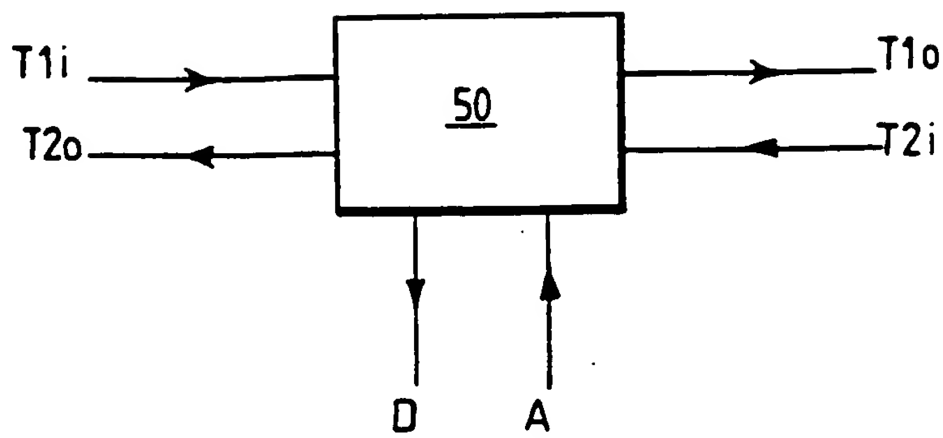


FIG.7A.

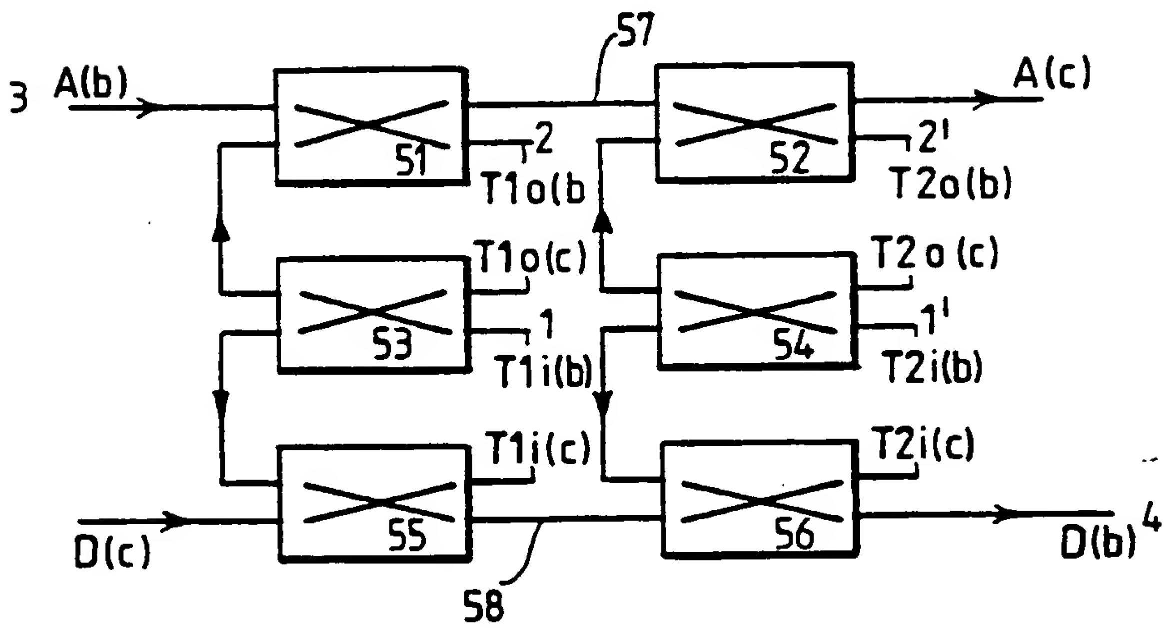


FIG.7B.

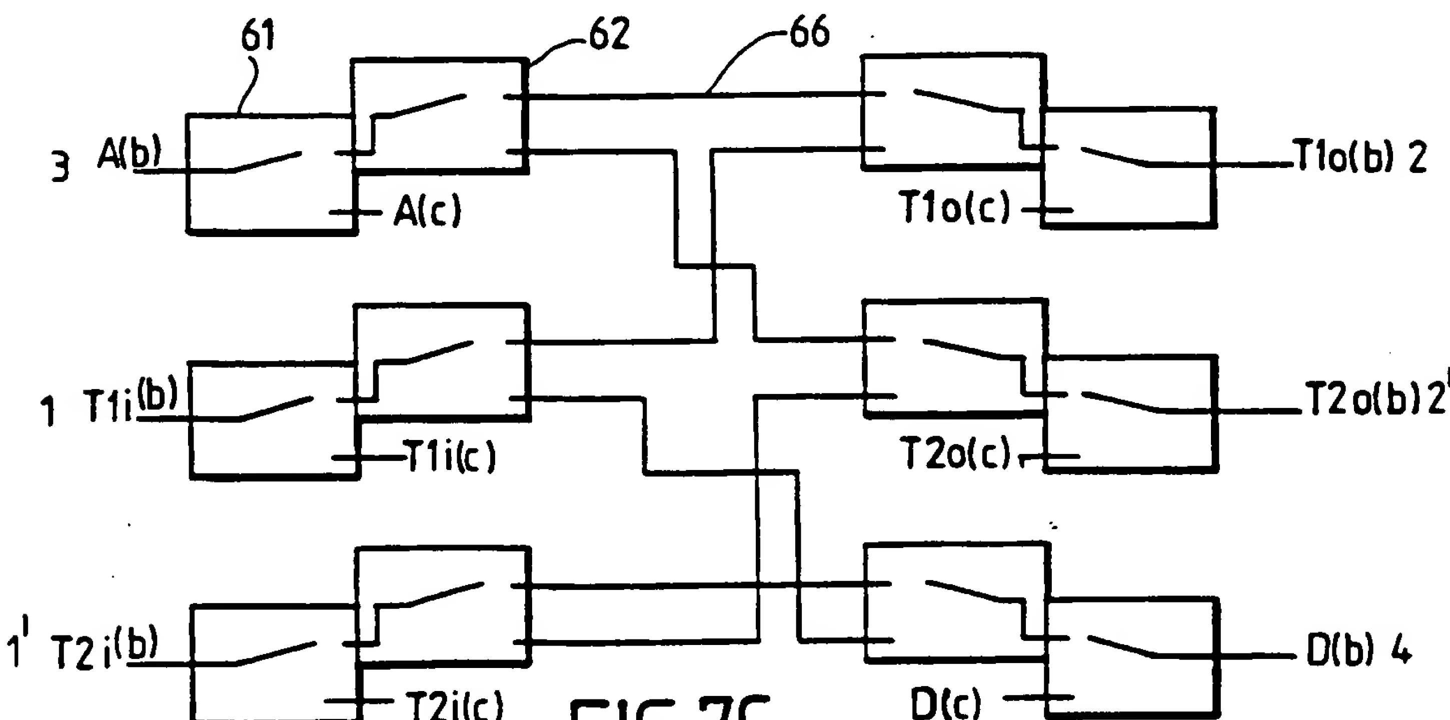


FIG.7C.

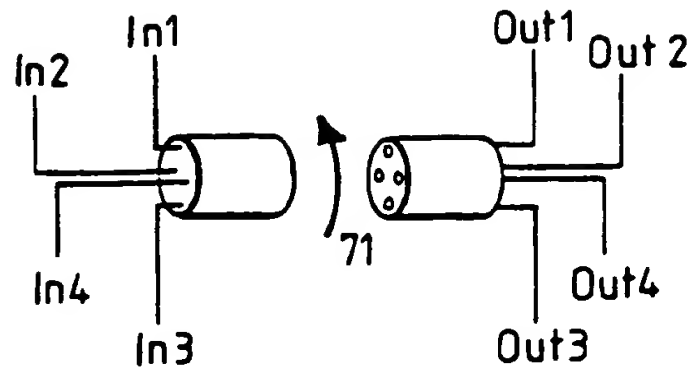


FIG.8A.

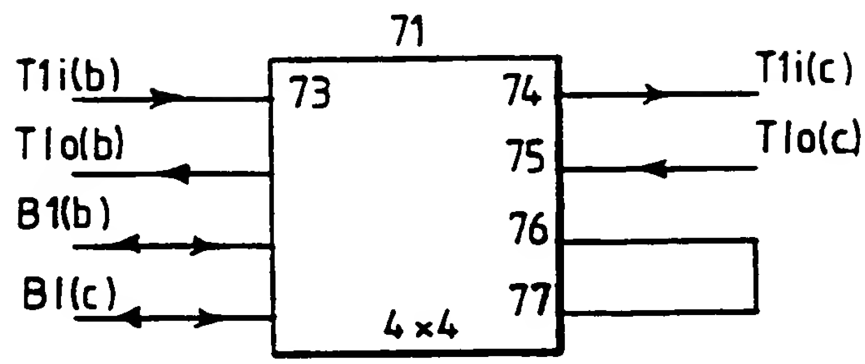


FIG.8B.

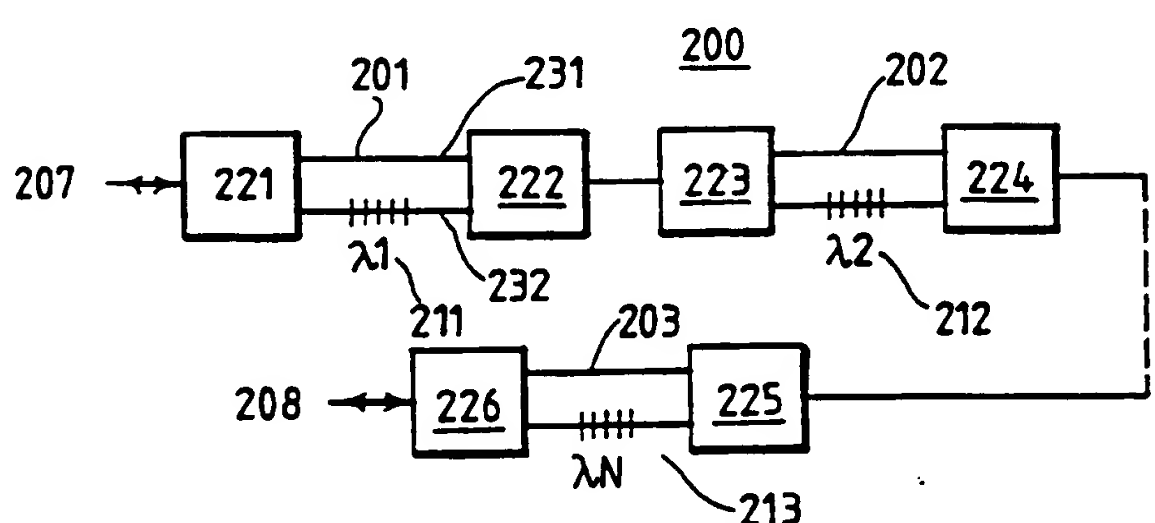
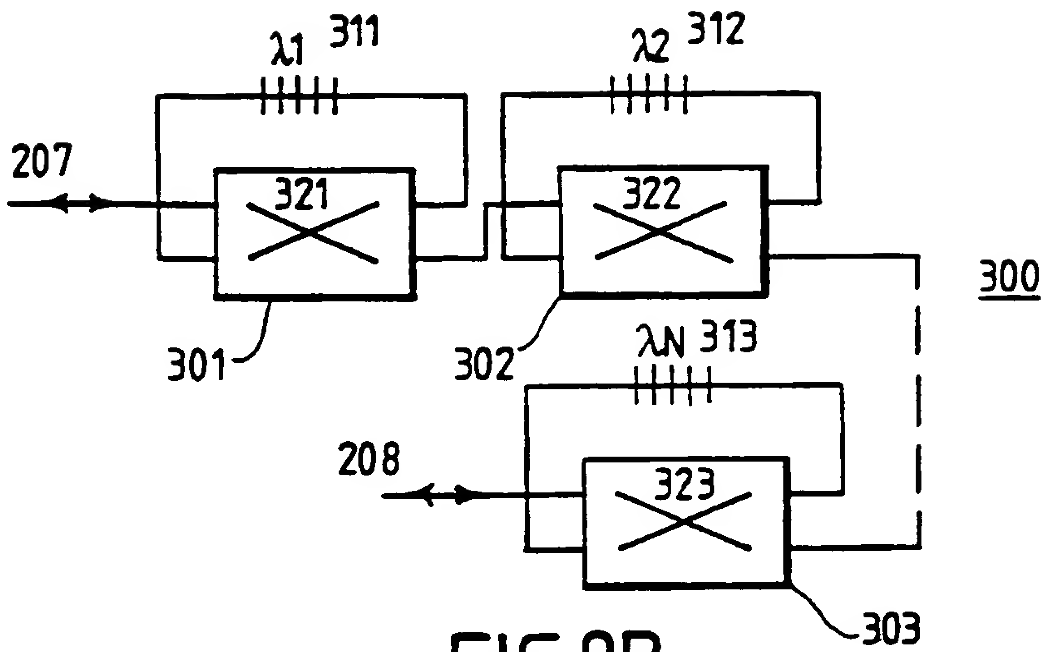


FIG.9A.


λ1
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λ2
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207
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301
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λN
313
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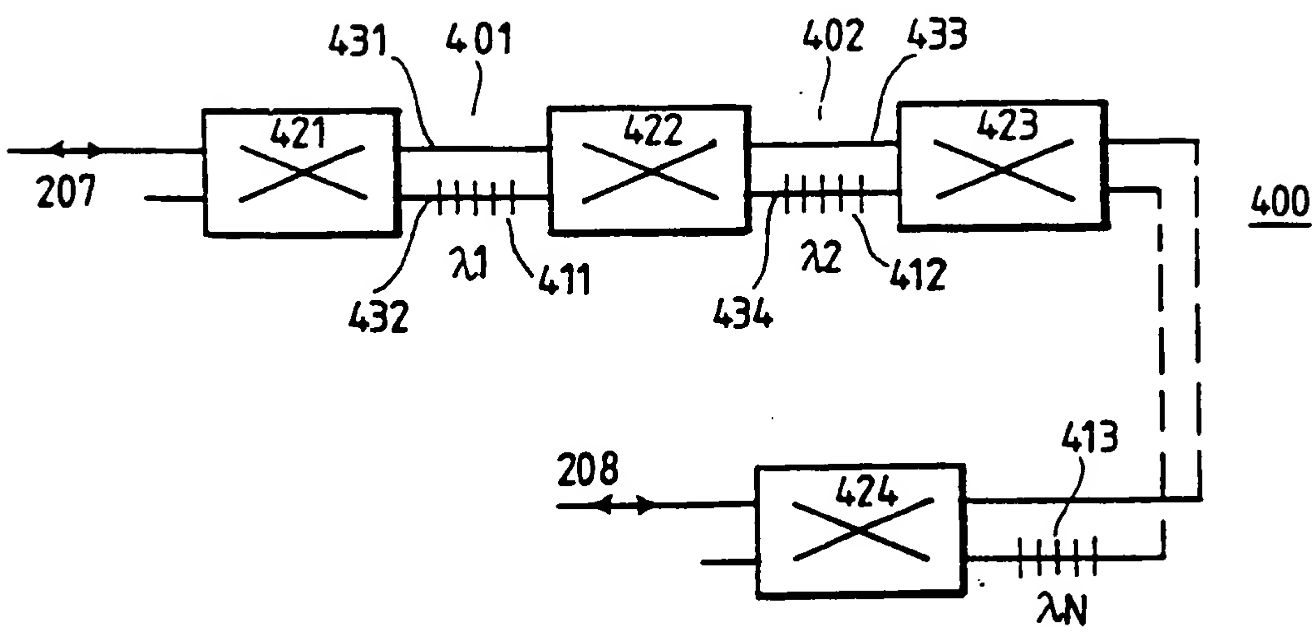
323
303

FIG.9B.


431
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λ1
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λ2
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λN

FIG.9C.

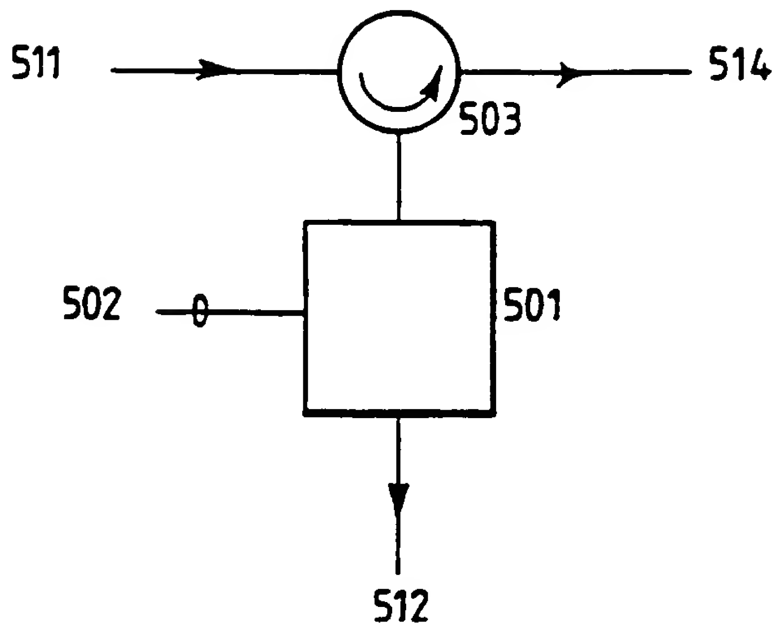

FIG.10.

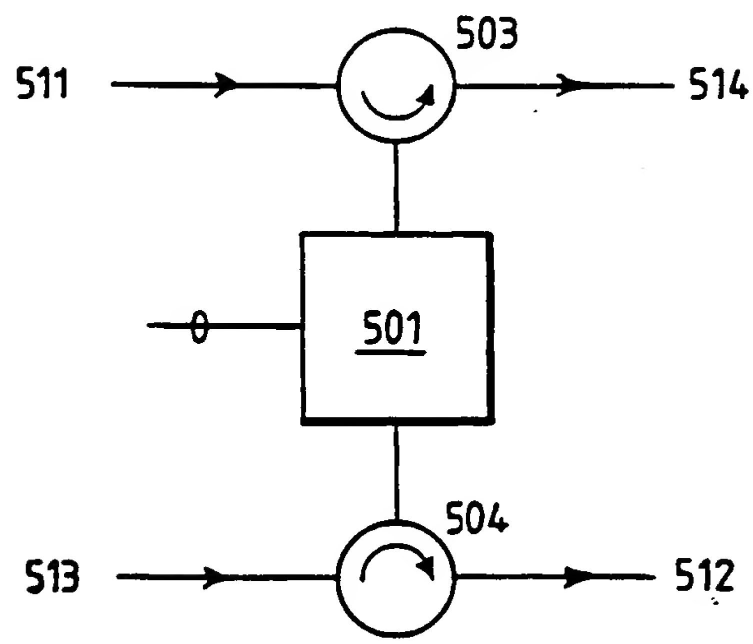

FIG.11.

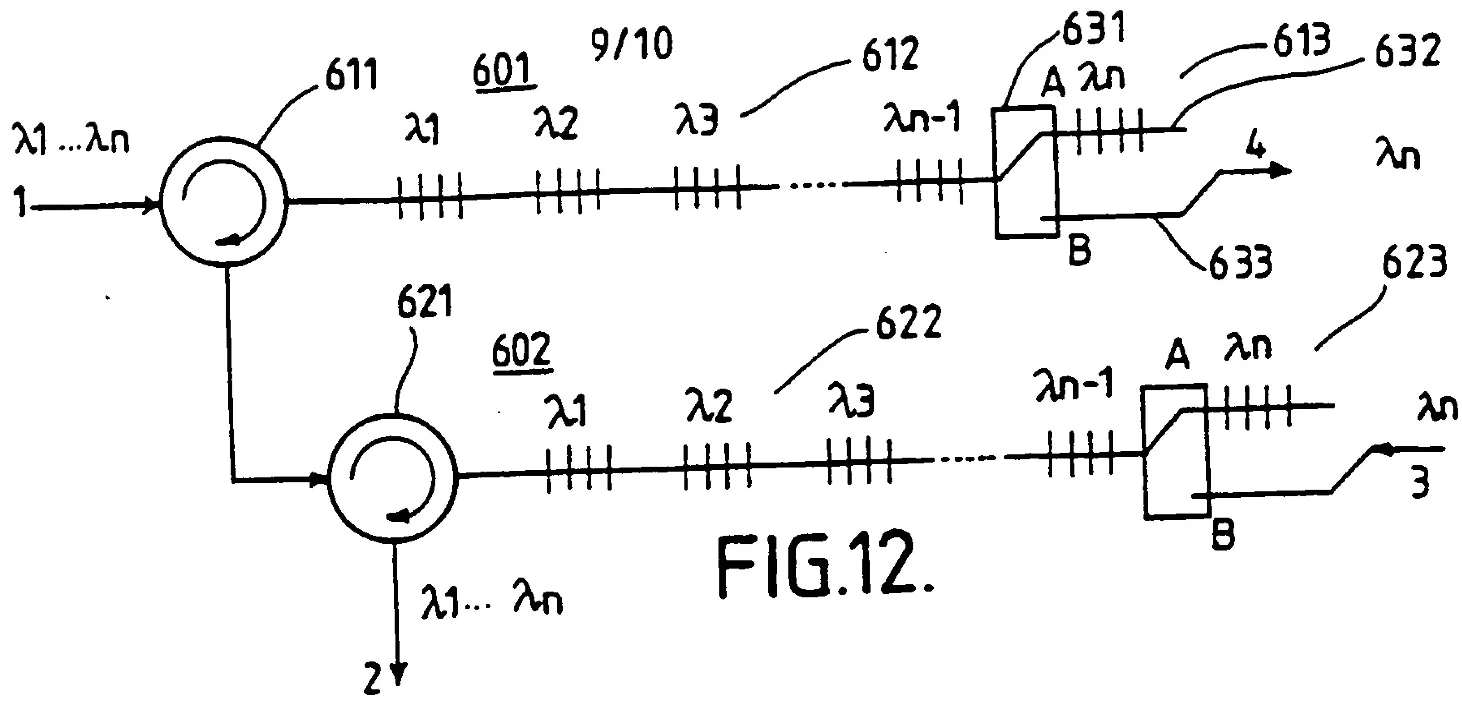

FIG.12.

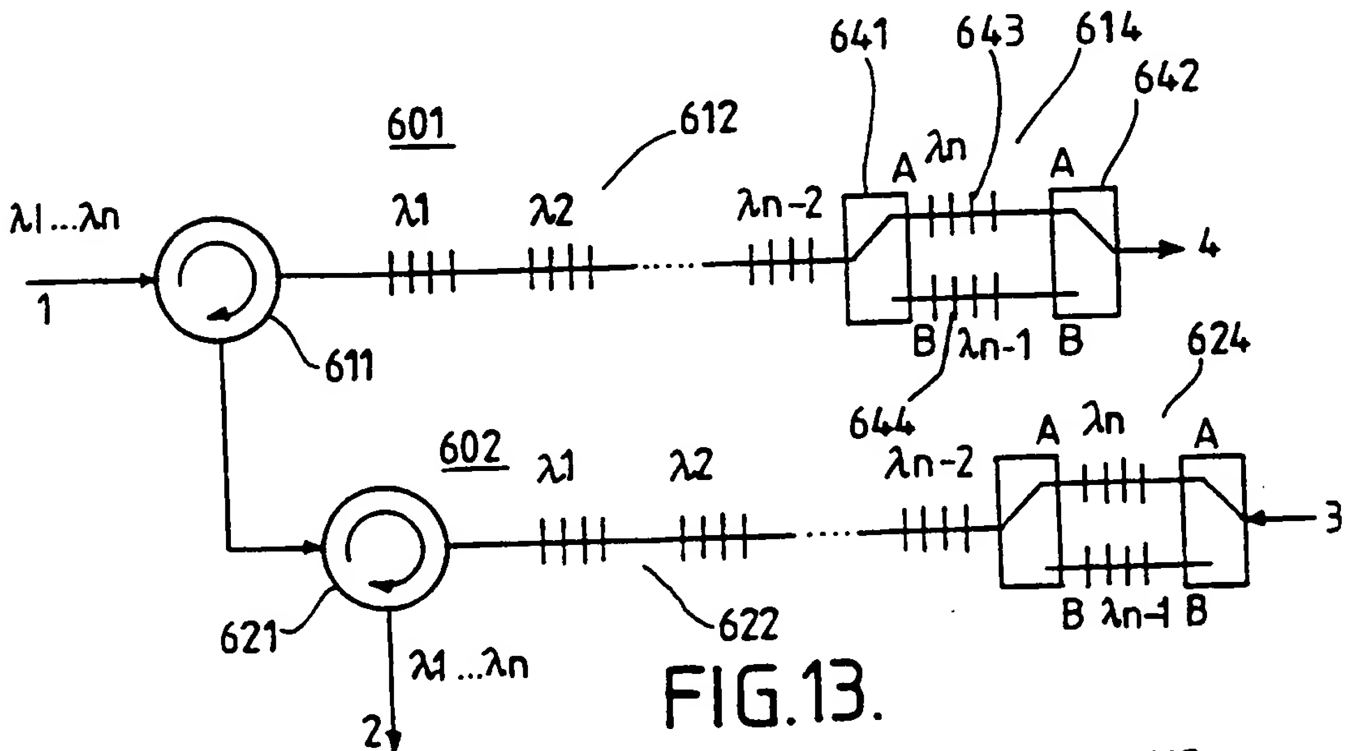

FIG.13.

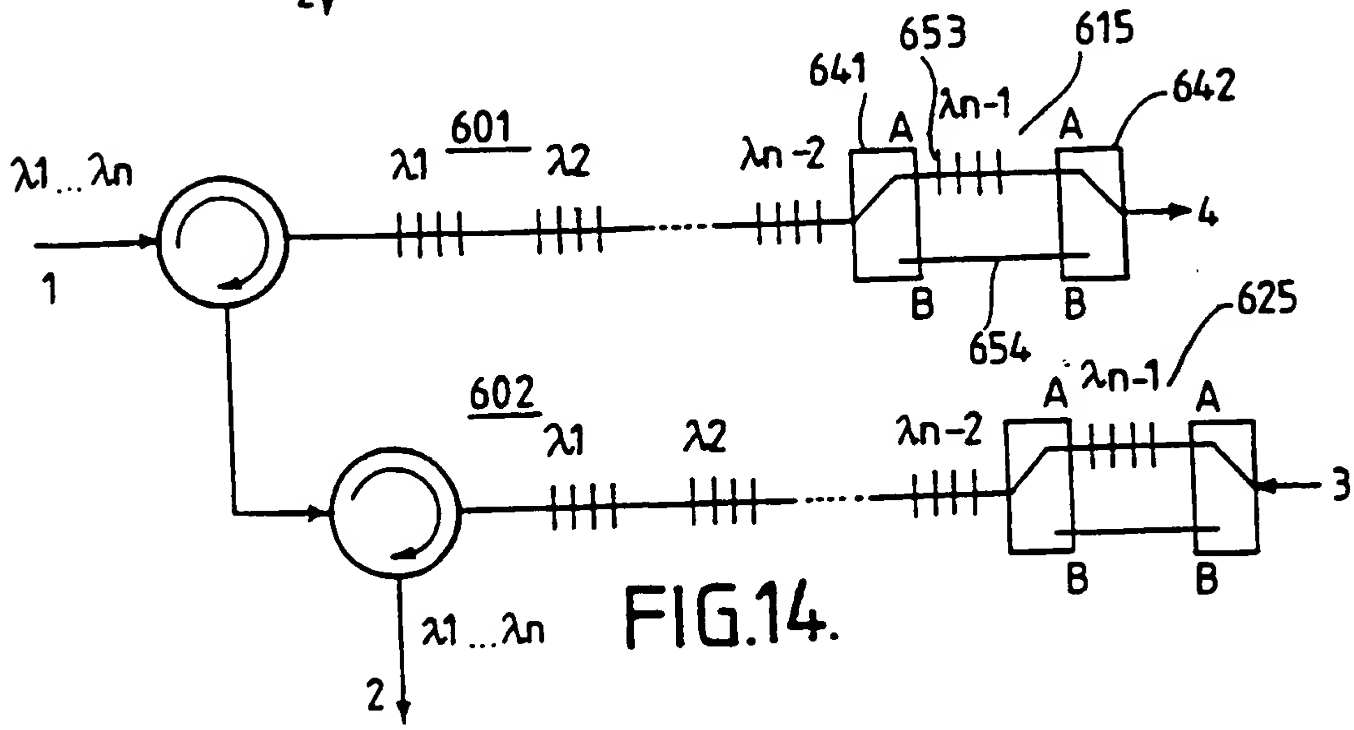

FIG.14.

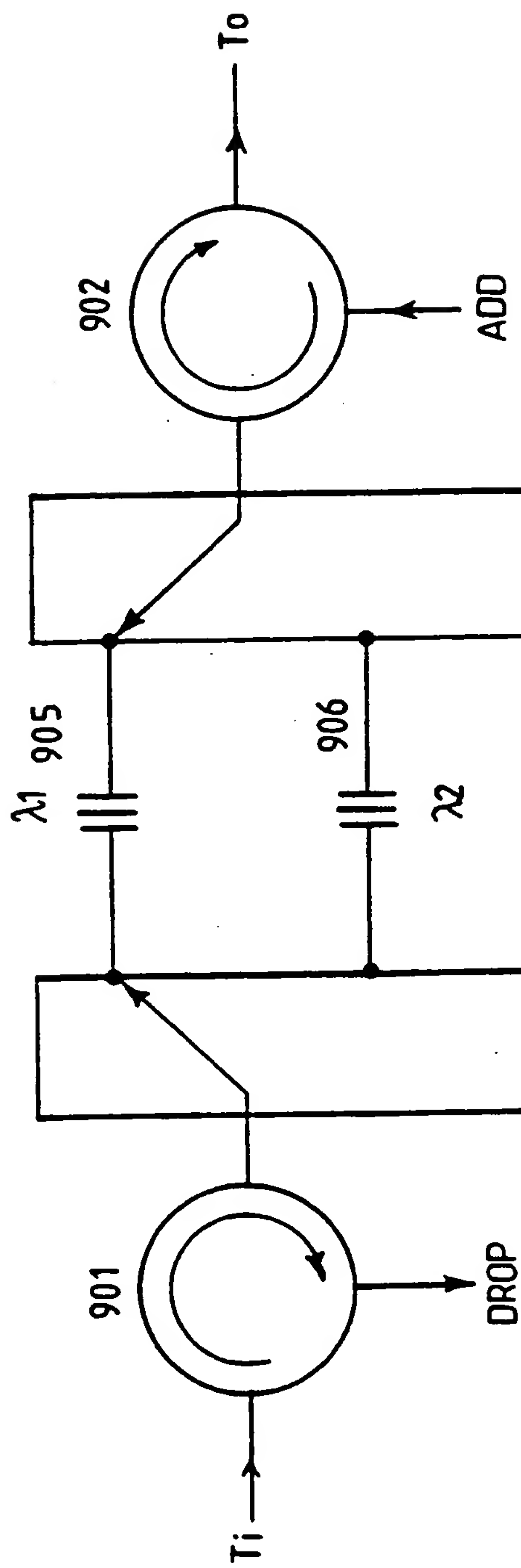

FIG.15.

INTERNATIONAL SEARCH REPORT

Intern··al Application No
PCT/GB 96/01890

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04J14/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
5 November 1996	29.11.1996
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Canali, F

Form PCT/ISA/210 (second sheet) (July 1992)

Intern ...al Application No
PC1/GB 96/01890

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	IEEE INFOCOM ' 93. THE CONFERENCE ON COMPUTER COMMUNICATIONS PROCEEDINGS. TWELFTH ANNUAL JOINT CONFERENCE OF THE IEEE COMPUTER AND COMMUNICATIONS SOCIETIES. NETWORKING: FOUNDATION FOR THE FUTURE (CAT. NO.93CH3264-9), SAN FRANCISCO, CA, USA, 28 MARCH-, ISBN 0-8186-3580-0, 1993, LOS ALMITOS, CA, USA, IEEE COMNPUT. SOC. PRESS, USA, pages 578-585 vol.2, XP000399037 LEE K -C ET AL: "Routing and switching in a wavelength convertible optical network"	1-5,13, 43,55, 56,73
A	see page 578, right-hand column, line 13 - line 25	6-12, 14-43, 57-72, 74-76
	see page 579, right-hand column, line 12 - line 27 see page 581, left-hand column, line 9 - right-hand column, line 17 ---	
X	US,A,4 906 064 (CHEUNG) 6 March 1990	1-5,43, 55,73
A	see column 1, line 48 - line 62	6-42, 44-54, 56-72, 74-76
	see column 2, line 12 - line 51 see column 3, line 23 - line 52 see column 6, line 64 - column 7, line 8 ---	
X	INTERNATIONAL CONFERENCE ON INTEGRATED BROADBAND SERVICES AND NETWORKS (CONF. PUBL. NO.329), LONDON, UK, 15-18 OCT. 1990, 1990, LONDON, UK, IEE, UK, pages 63-67, XP000410579 HILL G R ET AL: "Applications of wavelength routing in a core telecommunication network"	1,43,55, 73
A	* the whole document * ---	2-42, 44-54, 56-72, 74-76
A	IEE PROCEEDINGS J (OPTOELECTRONICS), OCT. 1993, UK, vol. 140, no. 5, ISSN 0267-3932, pages 309-315, XP000412793 GILLNER L: "Properties of optical switching networks with passive or active space switches" * the whole document * -----	1,43,55, 73

1

INTERNATIONAL SEARCH REPORT

. .rmation on patent family members

Interna· ·l Application No
PCT/uB 96/01890

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A-4906064	06-03-90	CA-A,C 2000646	30-06-90